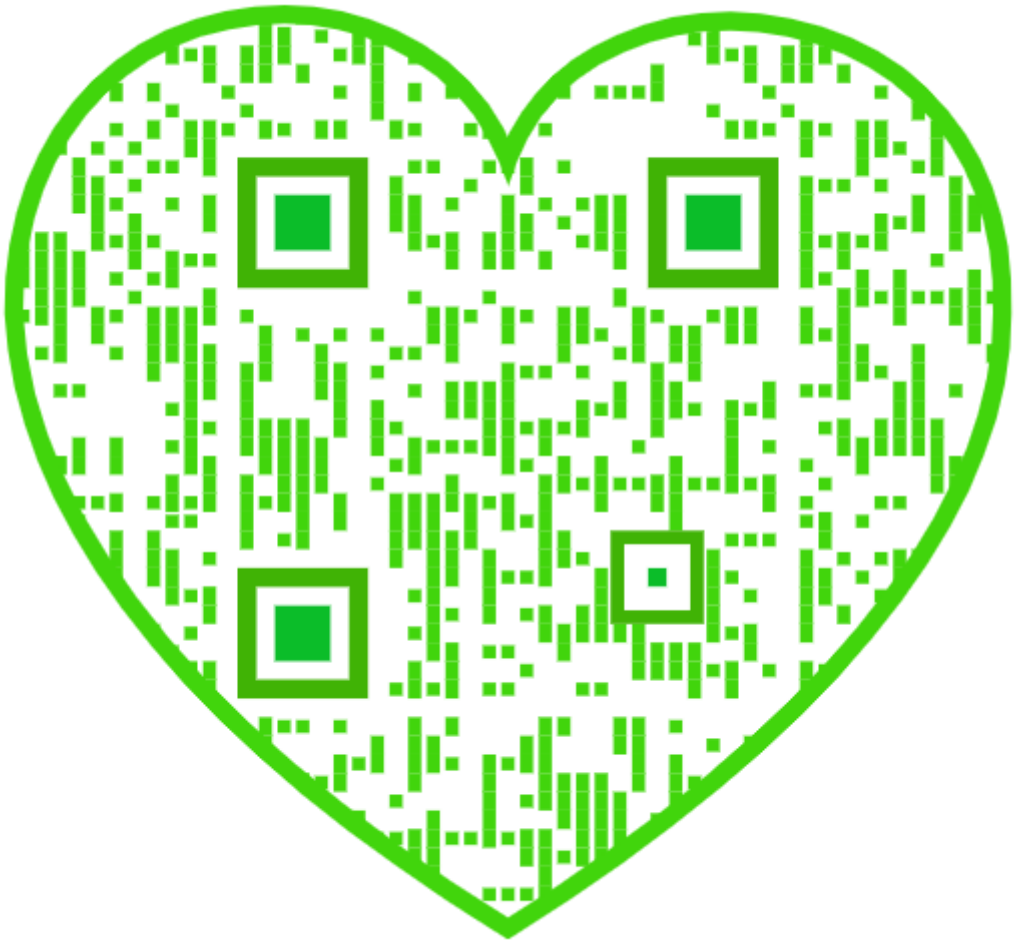

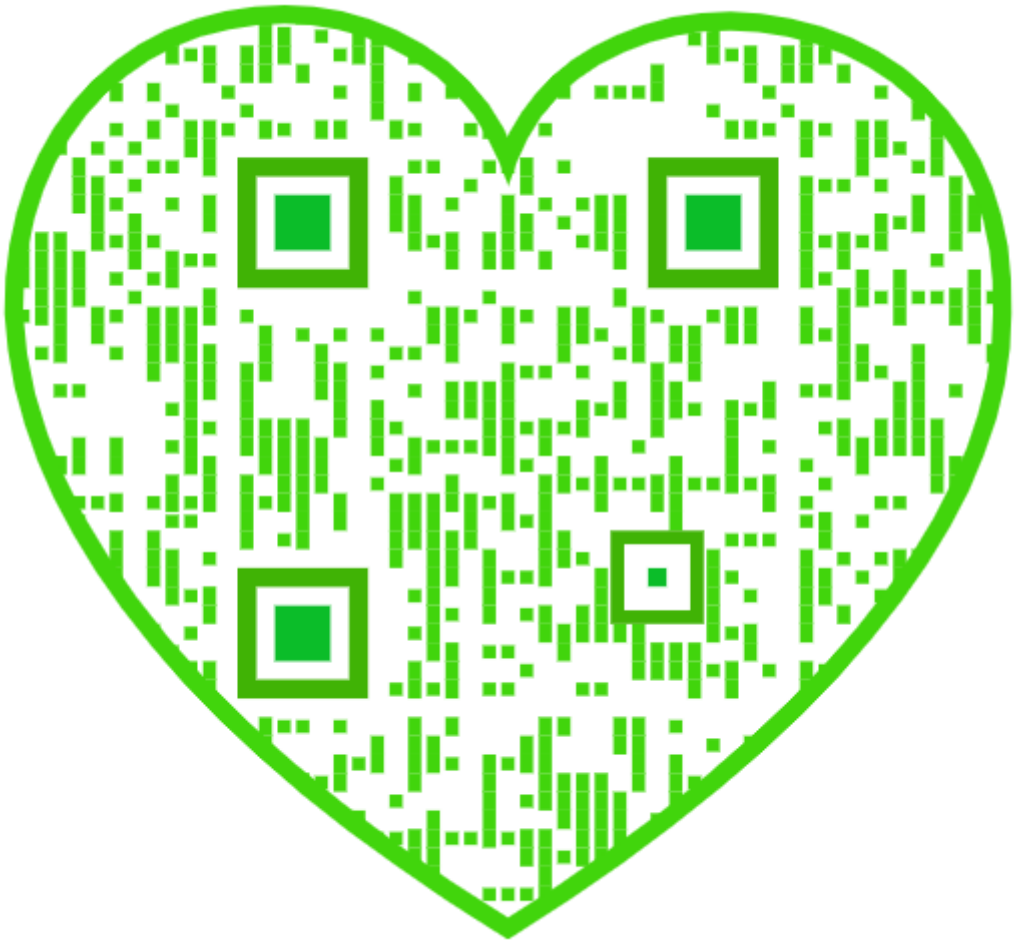

SANITARY REFRIGERATION AND ICE MAKING

By J. J. COSGROVE

Author of

Principles and Practice of Plumbing
Sewage Purification and Disposal
History of Sanitation
Wrought Pipe Drainage Systems
Plumbing Plans and Specifications
Plumbing Estimates and Contracts
Design of the Turkish Bath
Rock Excavating and Blasting

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PREFACE

THE VARIED USES of mechanical refrigeration and the increasing number of refrigerating and ice-making plants, call for a treatment of this important subject which is graphical rather than mathematical, practical rather than theoretical, and will be of use in the class room, the engine room and the office.

There is nothing new in this volume to the experimenter and student of entropy. It is written for the architect, mechanical engineer, refrigeration engineer, stationary engineer, plumber, ice-making and cold-storage superintendent, and the class room.

J. J. COSGROVE

Philadelphia, Pa.,
December 15, 1914.

ON the publisher's note, printed in the various books which preceded this volume, we endeavored to make clear our connection with the publication of technical works, and for the benefit of the readers of this volume we repeat the story of our relation as Publisher's and Manufacturer's.

The primary object of our organization is, as is universally known, to manufacture and market "Standard" Plumbing Fixtures, Brass Goods and other products made in our factories. In the development of an organization to accomplish this result, there has been established a Publishing Department, and "Sanitary Refrigeration and Ice Making" is part of the work of this Department.

"Sanitary Refrigeration and Ice Making" as well as "Principles and Practice of Plumbing," "Sewage Purification and Disposal," "History of Sanitation," "Wrought Pipe Drainage Systems," "Plumbing Plans and Specifications," "Plumbing Estimates and Contracts" and "Design of the Turkish Bath," are the work of the same author, Mr. J. J. Cosgrove, who is recognized as one of the leading authorities on the questions upon which he writes.

Standard Sanitary Mfg. Co.

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SANITARY REFRIGERATION AND ICE MAKING

PART I

REFRIGERATION

CHAPTER I

PRINCIPLES OF REFRIGERATION

THEORY of Heat.—Heat and cold are but different degrees of the same phenomenon. When heat is spoken of the term is used comparatively to indicate that, as compared with something else, it possesses a higher temperature. For instance, water at ordinary temperature, 62° Fahrenheit, is considered cold, but compared with iron pipes or plates, chilled with brine to a temperature of 10° Fahrenheit below zero, the water would be considered warm.

Heat is a condition, not a substance. It cannot be seen, weighed or measured, except by the work it performs, or results it will accomplish. It is now a commonly accepted theory that heat is a wave motion, or vibration, of the ether that pervades space. All bodies are made up of minute particles, called molecules. When these molecules are at rest the body is cold. Conditions arise, however, that cause these molecules to vibrate rapidly, and impinging

against one another they are made to fly apart. The wider apart the molecules separate and the more rapidly they are caused to vibrate the hotter will become the body. The vibrations of the molecules of one body cause the ether surrounding that body to vibrate in the same cadence, or time, and the vibrations radiating in all directions, in wave-like motions, strike the surrounding or near-by bodies, setting up similar motions in the molecules composing them, consequently increasing the molecular activity and causing them to become hotter. The ether, which propagates heat waves to surrounding objects, is a supposed medium filling all known space, even within the densest of bodies, as, for instance, air fills the spaces between grains of sand. This medium is thought to be more elastic than ordinary forms of matter, and to be sensitive to only certain forms of energy, such as light, heat and electricity. Magnetic and electric phenomena can be explained only as due to strains and pulsations in this ether.

Temperature.—The temperature of a body may be considered as a measure of the velocity with which its molecules vibrate to and fro. Each degree of heat which a body possesses sends forth a certain wave vibration peculiar to that temperature only, and the velocity of the ether waves increases with each increase and decreases with each decrease of temperature. The relation between temperature and vibration is absolute. That is, if a body be heated to a certain temperature it will send forth the wave peculiar to that temperature, and, conversely, if an ether wave strike a near-by object, it will heat that body to the

temperature corresponding to the wave. It is due to this phenomenon that temperature can be measured. If a small glass tube with a bulb on one end, filled with mercury, be brought near a heated body, the heat waves, striking the mercury, will set up the same velocity of vibration as in the heated body. As the vibrations of the molecules of mercury increase in velocity they fly further apart, thus occupying more space and forcing mercury up the tube a height corresponding to the temperature of the mercury and the velocity of the heat vibrations.

Thermometers.—Thermometers are instruments for measuring temperatures. The thermometers used in refrigeration practice are the Fahrenheit, abbreviated "F"; the Centigrade, abbreviated "C," and the Réaumur, abbreviated "R." The Fahrenheit, Centigrade and Réaumur thermometers are made alike, according to the same principle, and differ only in their graduations. The instrument consists of a glass tube, with a bulb on one end and closed at the other end to keep out air. Before closing the tube the bulb is filled with mercury and the air is driven out of the tube by heating the mercury to near its boiling point, thus filling the tube with mercury vapor. While the tube is in this condition it is sealed and, upon cooling, the vapor becomes condensed and a partial vacuum results.

Thermometers indicate temperature by the expansion of the mercury when heat is applied and by the contraction of the mercury when heat is withdrawn. Heat causes the mercury column to rise, while withdrawal of heat causes the mercury column

to fall, and the mercury within rises or falls an equal distance for equal changes of temperature; consequently, when the instrument is properly made, with the same inside diameter throughout the tube, and is accurately graduated, it will indicate with great accuracy any change of temperature.

To graduate a Fahrenheit thermometer it is placed on melting ice, and the point to which the mercury falls in the glass tube indicates the freezing point of water, which is marked 32°. The thermometer is next placed in the steam rising from water boiling in an open vessel at sea level, and the point to which the mercury rises in the glass tube indicates the boiling point of water, and is marked 212°. Having these two points fixed the intermediate space is divided into 180 equal parts, each of which represents 1°. Thirty-two parts, each equal to one of the divisions above the freezing point, are now marked off from the freezing point downward, and the last one is marked zero (0°). Fahrenheit placed the zero point of his thermometer at 32° below freezing, because that was the lowest temperature he could obtain, and he supposed it was impossible to obtain a lower one.

The graduations on a thermometer, to be accurate, should be marked on the glass tube, because when marked on a metal or wood background, as is done on house thermometers, the scale might become displaced and the instrument would then be too inaccurate for refrigeration readings.

The Centigrade thermometer is graduated by placing the zero at the freezing point of the Fahrenheit scale and marking the boiling point 100°. The distance between the freezing point and the boiling point

is then divided into 100 equal spaces, each of which represents a degree Centigrade. The equal divisions of the Centigrade scale may be carried as far above the boiling point and as far below the freezing point as is desired.

On the Réaumur thermometer the freezing point is marked zero and the boiling point 80°. The distance between these two points is then divided into 80 equal spaces, each of which represents 1 degree Réaumur. The spaces can be carried above the boiling point and below the freezing point, as in the case of the Centigrade thermometer.

A comparison of the readings, or scales, of Fahrenheit, Centigrade and Réaumur thermometers can be found in Table I.

The readings on a Centigrade thermometer can be converted into corresponding readings on the Fahrenheit scale by adding 32 to 9/5 of the Centigrade reading. This can be expressed by the formula:

$$\text{Fahrenheit} = 9/5C + 32$$

EXAMPLE.—What is the reading on a Fahrenheit scale corresponding to 66° on the Centigrade scale.

SOLUTION: 9/5 of 66 = 118.8 + 32 = 150.8° Fahrenheit.

Readings on the Réaumur thermometer can be converted into corresponding readings on the Fahrenheit scale by adding 32 to 9/4 of the Réaumur reading. This can be expressed by the formula:

$$\text{Fahrenheit} = 9/4R + 32$$

EXAMPLE.—What reading on the Fahrenheit scale will correspond to 52° on the Réaumur scale?

SOLUTION: 9/4 of 52 = 117 + 32 = 149° Fahrenheit.

TABLE I

COMPARISON OF THERMOMETERS

Cent	Réau.	Fahr.	Cent.	Réau.	Fahr.
—40	—32.0	—40.0	41	32.8	105.8
—38	—30.4	—36.4	42	33.6	107.6
—36	—28.8	—32.8	43	34.4	109.4
—34	—27.2	—29.2	44	35.2	111.2
—32	—25.6	—25.6	45	36.0	113.0
—30	—24.0	—22.0	46	36.8	114.8
—28	—22.4	—18.4	47	37.6	116.6
—26	—20.8	—14.8	48	38.4	118.4
—24	—19.2	—11.2	49	39.2	120.2
—22	—17.6	—7.6	50	40.0	122.0
—20	—16.0	—4.0	51	40.8	123.8
—18	—14.4	—0.4	52	41.6	125.6
—16	—12.8	+3.2	53	42.4	127.4
—14	—11.2	6.8	54	43.2	129.2
—12	—9.6	10.4	55	44.0	131.0
—10	—8.0	14.0	56	44.8	132.8
—8	—6.4	17.6	57	45.6	134.6
—6	—4.8	21.2	58	46.4	136.4
—4	—3.2	24.8	59	47.2	138.2
—2	—1.6	28.4	60	48.0	140.0
0	0.0	32.0	61	48.8	141.8
+1	+0.8	33.8	62	49.6	143.6
2	1.6	35.6	63	50.4	145.4
3	2.4	37.4	64	51.2	147.2
4	3.2	39.2	65	52.0	149.0
5	4.0	41.0	66	52.8	150.8
6	4.8	42.8	67	53.6	152.6
7	5.6	44.6	68	54.4	154.4
8	6.4	46.4	69	55.2	156.2
9	7.2	48.2	70	56.0	158.0
10	8.0	50.0	71	56.8	159.8
11	8.8	51.8	72	57.6	161.6
12	9.6	53.6	73	58.4	163.4
13	10.4	55.5	74	59.2	165.2
14	11.2	57.2	75	60.0	167.0
15	12.0	59.0	76	60.8	168.8
16	12.8	60.8	77	61.6	170.6
17	13.6	62.6	78	62.4	172.4
18	14.4	64.4	79	63.2	174.2
19	15.2	66.2	80	64.0	176.0
20	16.0	68.0	81	64.8	177.8
21	16.8	69.8	82	65.6	179.6
22	17.6	71.6	83	66.4	181.4
23	18.4	73.4	84	67.2	183.2
24	19.2	75.2	85	68.0	185.0
25	20.0	77.0	86	68.8	186.8
26	20.8	78.8	87	69.6	188.6
27	21.6	80.6	88	70.4	190.4
28	22.4	82.4	89	71.2	192.2
29	23.2	84.2	90	72.0	194.0
30	24.0	86.0	91	82.8	195.8
31	24.8	87.8	92	73.6	197.6
32	25.6	89.6	93	74.4	199.4
33	26.4	91.4	94	75.2	201.2
34	27.2	93.2	95	76.0	203.0
35	28.0	95.0	96	76.8	204.8
36	28.8	96.8	97	77.6	206.6
37	29.6	98.6	98	78.4	208.4
38	30.4	100.4	99	79.2	210.2
39	31.2	102.2	100	80.0	212.0
40	32.0	104.0			

Reading on the Fahrenheit thermometer can be converted into readings on the Centigrade scale by multiplying the remainder by 5/9. Expressed as a formula:

Centigrade = 5/9(F — 32)

EXAMPLE.—What reading on the Centigrade thermometer will correspond to 80° on the Fahrenheit scale?

SOLUTION: 80 — 32 = 48 × 5/9 = 26.6° Centigrade.

Reading on the Réaumur thermometer can be converted into corresponding readings on the Centigrade scale by multiplying the Réaumur reading by 5/4. Expressed as a formula:

Centigrade = 5/4R

EXAMPLE.—What reading on the Centigrade scale will correspond to 45° on the Réaumur scale?

SOLUTION: 5/4 × 45 = 56.25° Centigrade.

Readings on the Fahrenheit thermometer can be converted into corresponding readings on the Réaumur scale by subtracting 32 from the Fahrenheit reading, then multiplying by 4/9. Expressed as a formula:

Réaumur = 4/9(F — 32)

EXAMPLE.—What reading on the Réaumur thermometer will correspond to a reading of 203° on the Fahrenheit thermometer?

SOLUTION: 203 — 32 = 171 × 4/9 = 67° Réaumur.

Reading on the Centigrade thermometer can be converted to corresponding readings on the Réaumur scale by multiplying the Centigrade reading by 4/5. Expressed as a formula:

Réaumur = 4/5C

EXAMPLE.—What reading on the Réaumur thermometer corresponds to a reading of 95° on the Centigrade scale?

SOLUTION: $4/5 \times 95 = 76°$ Réaumur.

In order to distinguish the temperatures below the zero point from those above, the minus sign (—) is placed before all figures indicating the number of degrees below zero. Thus, —10°F. is read 10° Fahrenheit below zero, and means that the temperature is 10° below zero, according to the Fahrenheit thermometer.

ABSOLUTE TEMPERATURE.—When Fahrenheit obtained a temperature of 32° below freezing he supposed that he had reached absolute zero. It has been found by experiment, however, that all perfect gases will expand 1–460 of their volumes when heated from zero to 1° above it, if the pressure remains constant. From this fact it is inferred that the ultimate limit of contraction is 460° below zero on the Fahrenheit scale, and that at this point all motion of the molecules ceases. The point 460° below zero on the Fahrenheit scale is called the *absolute zero* of temperature and temperatures measured from absolute zero are known as *absolute temperatures*.

Absolute temperatures are not indicated on ordinary thermometers, and when the absolute temperature is desired it must be found by adding a suitable constant to the thermometer reading. The constant for a Fahrenheit thermometer is 460°, for a Centigrade thermometer 273-1/3° and for a Réaumur thermometer 219°. If, however, the thermometer registers below zero the number of degrees registered must be subtracted from 460°, 273-1/3° or 219°,

according to whether Fahrenheit, Centigrade or Réaumur thermometer is used. For example, if a temperature of 60° were indicated on a Fahrenheit thermometer the absolute temperature would be 460° + 60° = 520°. If, on the other hand, a temperature of —10° were indicated on a Fahrenheit thermometer the absolute temperature would be 460° — 10°, or 450°. Absolute temperatures of gas are used in refrigeration practice in calculating adiabatic and isothermal expansion and compression of gases. When the temperature of a substance is mentioned that indicated by a thermometer is understood, unless it is stated to be "absolute temperature."

Measurement of Heat.—Temperature is not a measure of the quantity of heat a body possesses but of the velocity of vibrations of the molecules. Heat, on the other hand, may be considered the total energy of the molecules composing the body. For instance, a knitting needle heated to a white glow would have a higher temperature than an iron bar heated only moderately warm, but the iron bar would possess a greater amount of heat. This could be determined by placing the needle and the bar each in a separate vessel containing equal amounts of water, and noting the rise in temperature of the water. Further, a ball of metal 1 foot in diameter might have the same temperature as another ball of metal 1 inch in diameter, but the larger ball would have the greater quantity of heat.

Heat is measured by the effect it produces on a known weight of water. For instance, if a certain quantity of heat will raise the temperature of 1 pound

of water 10° Fahrenheit, it will raise the temperature of 10 pounds of water 1° Fahrenheit, or of 100 pounds of water 0.1° Fahrenheit; clearly, then, there is some relation between heat and the quantity of water it will raise 1° in temperature, and this relation is measured by the *unit of heat*, known as a *British Thermal Unit.* A British thermal unit, abbreviated B. T. U., is the quantity of heat required to raise the temperature of 1 pound of water from 62° Fahrenheit to 63° Fahrenheit. In practice it is taken as the quantity of heat required to raise the temperature of 1 pound of water 1° Fahrenheit. British thermal units are commonly spoken of in practice as heat units, so the two terms may be considered synonymous.

As a matter of fact, for temperatures above 63° Fahrenheit it takes slightly more than 1 British thermal unit to produce a change of 1° in 1 pound of water, and, conversely, for temperatures below 62° Fahrenheit it takes slightly less than 1 British thermal unit to produce a change of 1° in 1 pound of water. Further, the higher the temperature of the water becomes the greater the amount of heat required to raise its temperature 1°, and the lower the temperature of the water becomes the less the amount of heat required to raise the temperature 1°. For instance more heat would be required to raise the temperature of 1 pound of water from 70° to 71° Fahrenheit than would be required to raise the temperature of the same quantity of water from 69° to 70° Fahrenheit. This difference is so slight, however, that in practice it is ignored.

Specific Heat.—Different substances possess different capacities for the absorption of heat, for,

just as a sponge will take up far more water than will an equal size and weight of cotton or woolen cloth, so will some substances take up or absorb many times the amount of heat that others will. For instance, if a 1-pound iron ball be heated to the temperature of boiling water, 212° F., and placed in a vessel into which water of a temperature of 60° F. is slowly poured until the temperature of the ball is lowered to 70° F., the temperature of the water meantime having risen to the same degree, it will be found that 1.62 pounds of water have been raised in temperature 10°.

If a similar iron ball be heated to a like temperature and placed in a vessel into which mercury of a temperature of 60° F. is slowly poured, until the iron ball and mercury reach a common temperature of 70°, it will be found that in cooling from 212° to 70° the iron ball has raised the temperature of 48.5 pounds of mercury 10°. Obviously, then, it will take about thirty times the amount of heat to raise the temperature of a given weight of water to any desired degree, that would be required to heat a like weight of mercury to the same temperature; and, what is more to the point in refrigeration practice, as action and reaction are equal but opposite, it would take thirty times the amount of refrigeration effort to cool a quantity of water that would be required to cool a like amount of mercury. This is an important principle to keep in mind in studying or applying refrigeration, for it is this specific heat in goods placed in storage which must be abstracted, and knowing the specific heat of various substances makes simple the problem of computing the cooling effect required in given cases.

The specific heat both above and below the freezing temperature, latent heat of freezing. together with composition of various substances commonly stored in refrigeration plants, can be found in Table II.

TABLE II

SPECIFIC AND LATENT HEAT OF VARIOUS FOOD PRODUCTS

Substance	Composition		Specific Heat Above Freezing in Heat Units	Specific Heat Below Freezing in Heat Units	Latent Heat of Freezing in Heat Units
	Water	Solids			
Lean Beef	72.00	28.00	0.77	0.41	102
Fat Beef	51.00	49.00	.60	.34	72
Veal	63.00	37.00	.70	.39	90
Fat Pork	39.00	61.00	.51	.30	55
Eggs	70.00	30.00	.76	.40	100
Potatoes	74.00	26.00	.80	.42	105
Cabbage	91.00	9.00	.93	.48	129
Carrots	83.00	17.00	.87	.45	118
Cream	59.25	30.75	.68	.38	84
Milk	87.50	12.50	.90	.47	124
Oysters	80.38	19.62	.84	.44	114
Whitefish	78.00	22.00	.82	.43	111
Eels	62.07	37.93	.69	.38	88
Lobster	76.62	23.38	.81	.42	108
Pigeon	72.40	27.60	.78	.41	102
Chicken	73.70	26.30	.80	.42	105

In this table the values are given in heat units per pound and the figures in the last column, showing the latent heat of freezing, have been obtained by multiplying the latent heat of freezing water, which is 142 heat units, by the per cent. of water contained in the different materials considered, for as the solid constituents remain in their original condition, only the liquid or watery portions of these materials are concerned in the solidification or freezing of them.

It will be seen by the table that to lower the temperature of different substances various amounts of heat would have to be abstracted to reduce the temperatures to the freezing points, and whenever

the preservation of the food product requires it to be maintained at a temperature lower than the freezing point still more specific heat must be abstracted. Take, for instance, the storage of fat pork. The specific heat of this product above freezing is .51, while that of cabbage is .93, the cabbage being 91 per cent. water. To cool ten tons of cabbage to just above freezing temperature, therefore, would take almost double the refrigerating effort required to cool an equal weight of fat pork.

The specific heat of various substances used in and around refrigeration rooms can be found in Table III. Some of the substances here enumerated will probably be used in the construction and equipment of the building, others for vats and receptacles, while still others form part of the goods stored.

TABLE III

SPECIFIC HEAT OF VARIOUS SUBSTANCES

Cast Iron	.130	Coal	.241
Brass	.094	Sulphur	.202
Mercury	.033	Coke	.203
Tin	.056	Alcohol	.659
Zinc	.095	Oil	.310
Chalk	.215	Vinegar	.920
Stone	.270	Strong brine	.700
Masonry	.200	Ice	.504
Oak wood	.570	Water, at 32° F.	1.000
Pine	.650	Air	.238
Glass	.194		

The specific heat of a substance is the ratio between the quantity of heat required to warm that body 1° Fahrenheit and the quantity of heat required to warm an equal weight of water 1°. Water at 32° Fahrenheit is called 1 and the specific heat of other substances is expressed by giving, decimally, the value of the ratio. For instance, as was previously

pointed out, the specific heat of mercury is as 1 to 30, or 1–30, which expressed decimally would be .0333. In refrigeration practice it is frequently necessary to find the number of heat units required to be extracted to lower the temperature of goods in storage. This information can be found by the following rule or formula:

RULE.—To find the number of heat units to be abstracted to lower the temperature of stored products a given number of degrees, multiply the specific heat of the substance by its weight in pounds and by the number of degrees the substance is to be cooled. Expressed as a formula:

$$H = SW(T - t)$$

In which

H = number of heat units to be abstracted.

S = specific heat of the substance.

W = weight of substance in pounds.

T = higher temperature of the substance.

t = temperature to which substance must be lowered.

EXAMPLE.—How many heat units must be abstracted from 20 short tons of lean beef to lower its temperature from 70° Fahrenheit to 32° Fahrenheit?

SOLUTION.—Specific heat of lean beef, .77. Weight of beef, 40,000 pounds. Degrees temperature to be lowered, 70 — 32 = 38.

Substituting those values in the formula .77 × 40,000 × 38 = 1,170,400 B. T. U. (Answer.)

In figuring the refrigeration capacity of engines or coils the weight of various substances which can be cooled by abstracting a given amount of heat can be determined by the following rule:

RULE.—To find the weight in pounds of a substance that can be lowered in temperature by a certain amount of refrigeration effort, divide the number of heat units to be extracted by the product of the specific heat of the substance and the number of degrees the substance is to be lowered. Expressed as a formula:

$$W = \frac{H}{S\,(T - t)}$$

In which:

W = weight of substance in pounds.
H = number of heat units to be abstracted.
S = specific heat of the substance.
T = higher temperature of the substance.
t = temperature to which substance must be lowered.

EXAMPLE.—How many pounds of lean beef can be lowered in temperature from 70° to 32° Fahrenheit, by abstracting 1,170,400 heat units?

SOLUTION.—Substituting values in the formula just given:

$$\frac{1{,}170{,}400}{77 \times 38} = W = 40{,}000 \text{ pounds.} \quad \text{(Answer.)}$$

Sensible Heat.—All substances possess heat in three different states, or at all events are capable of possessing them at different times when exposed to the right set of conditions. Specific heat has already been explained, but mention was not made before of the fact that specific heat may be and generally is sensible heat. That is, it is perceptible to the feelings, and can be measured with thermometers. As a matter of

fact it is more the temperature than the quantity of heat that produces the quality called sensible, but whatever it may be called it is one of the least considered qualities or conditions in refrigeration practice, being used principally to indicate the temperatures of compartments and fluids used in the process, while the less perceptible specific heat and the insensible latent heat are the two qualities which must be reckoned with.

Latent Heat of Fusion and Evaporation.—Latent heat is the heat contained in a substance which is not perceptible to the senses or capable of being indicated by the most sensitive thermometers. When the application of heat causes a change of state in molecular construction of a substance and the substance passes either from a solid to a liquid, or from a liquid to a gaseous state, there is an absorption of heat without any rise in temperature, and the heat thus absorbed is termed latent heat, because it apparently disappears and is not measurable by a thermometer.

The heat is not lost, however, but reappears whenever the substance passes back again from the gaseous to the liquid state, or from the liquid to the solid state. The heat thus temporarily lost, or latent, is expended in overcoming the molecular cohesion of the particles of the substance and in overcoming the resistance of external pressure to change of volume of the heated body.

If heat be applied to a pound of ice there will be a rise in temperature until the freezing point, 32° F. is reached. At this point the ice will begin to melt,

but the temperature of the mixture of ice and water will remain 32° F. so long as any particle of ice remains in it, notwithstanding the fact that during the entire melting process the ice has been absorbing heat. The amount of heat thus absorbed in changing the state of a pound of ice from ice at 32° F. to water at the same temperature is 144 heat units, and this quantity is known as the *latent heat of fusion* of ice.

If the application of heat be continued to the water resulting from the pound of ice the temperature of the water will rise, but it will now require about twice as many heat units to effect a rise of 1° as it did to accomplish the same rise in the ice. The reason is that the specific heat of water is 1,00, while that of ice is only .504, consequently the water will absorb more heat, as was pointed out in the paragraph on specific heat.

When the water has reached a point of 212° Fahrenheit there will be a further absorption of heat with no increase of temperature. Boiling occurs and the heat absorbed is expended in transforming the water into steam. Water at atmospheric pressure at sea level cannot be heated beyond 212° Fahrenheit, and the steam which is formed is likewise at a temperature of 212° Fahrenheit.

When the entire pound of water has been evaporated into steam 965.8 British Thermal Units have been used in the operation, and the quantity so absorbed is known as the *latent heat of evaporation* of water.

The heat which is absorbed by one pound of water in converting it into steam at atmospheric pressure is sufficient to melt three pounds of steel or thirteen pounds of gold. This fact alone will explain

the tremendous power stored up in steam, ready to do useful work, so stored to reappear as heat when the process is reversed.

For, as action and reaction are equal, but opposite, so the latent heats of fusion and evaporation can be reversed and caused to do useful work in sanitary refrigeration and ice making. In fact, this principle is utilized in most of the refrigeration plants now erected, in which the abstraction of heat is brought about by the vaporization of some liquid having a low boiling point. Machines of this character may logically be considered latent heat refrigerating machines.

The reverse action of latent heat may be understood by considering the condensation of steam to water and the cooling of water and congealing, or freezing, into ice. If steam be allowed to condense in a coil immersed in an insulated vessel containing water and the number of heat units thus given off carefully ascertained, it will be found that one pound of steam at 212° Fahrenheit condensing to water at a temperature of 32° Fahrenheit will give off 965.8 British Thermal Units, which was the exact amount latent or apparently lost in the process of converting water at freezing temperature into steam at atmospheric pressure. During the process of condensation the temperature of the steam and water in contact would be uniformly 212° Fahrenheit until the steam was all condensed, when the temperature of the water would begin to fall until the freezing point, 32° Fahrenheit, was reached. At this temperature the formation of ice would begin, and 144 units of heat would be given off by the pound of water in forming ice without the temperature changing whatsoever.

The principal facts regarding latent heat are that in passing from a solid to a liquid state or from a liquid to a gaseous state they require, or absorb, heat; while conversely, in passing from a gaseous to a liquid state, or from a liquid to a solid state, they give off heat. The application of these principles will be found in refrigeration machines, where a suitable liquid, like anhydrous ammonia, is compressed and liquified in the cylinders of a compressor, cooled to ordinary temperature by water flowing over the storage coil, then allowed to expand to a gas in cooling coils, where the heat required for the process is obtained from the substance in storage.

Theoretically any volatile liquid may be used as a working fluid in a latent heat machine, but practically the fluid is not found suitable unless it possesses, in addition to a low vaporizing temperature, a high capacity for latent heat.

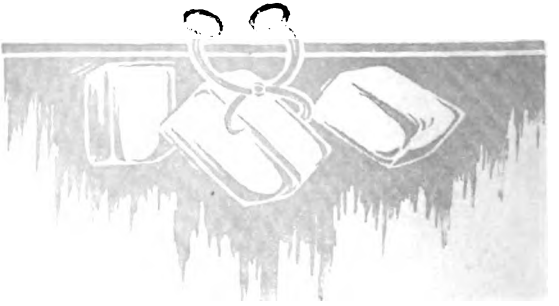
A list of substances that have been used in latent-heat machines, together with their boiling temperatures, latent heats and specific heats can be found in Table IV.

TABLE IV

LATENT HEATS OF FLUIDS

Substance	Temperature of Boiling Point Atmospheric Pressure	Latent Heat in British Thermal Units	Specific Heat of Liquid
Nitric acid	248° F.	....	....
Saturated brine	226° F.	....	....
Water	212° F.	966	1.0000
Alcohol	173° F.	....	....
Chloroform	140° F.	....	....
Ether, sulphurous	95° F.	170	.5299
Ether, methyl	—10° F.	....	....
Sulphur dioxide	14° F.	168.7	.4100
Anhydrous ammonia	—28.5° F.	573	1.0058
Carbon dioxide	—140° F.	141	.9550

It will be seen by the table that carbon dioxide has the lowest boiling point—140° Fahrenheit. The latent heat value, however, is comparatively low, so that it loses in that respect what it gains in the other. Anhydrous ammonia, on the other hand, has a sufficiently low boiling, or vaporizing, temperature, which, combined with high latent heat value, makes it the commonly accepted refrigerating fluid, although carbon dioxide is extensively used. In fact, the two refrigerants now commonly used in practice are anhydrous ammonia and carbon dioxide. Each of these refrigerants has its own particular advantages and disadvantages, and its own peculiar field of usefulness, which will be described in their proper places. The other refrigerants with the exception of sulphur dioxide have been practically abandoned as working fluids. Recently sulphur dioxide has been cleverly employed in a small, self-contained refrigerating machine.



TRANSFER OF HEAT

HEAT of Solutions.—Whenever a chemical action takes place the rearrangement of the molecules to form the new combination is accompanied by an increase or decrease of temperature, according to the nature of the change. Ordinary physical mixtures are not affected thermally, as no molecular change takes place, but chemical combinations and solutions are invariably accompanied by an increase or withdrawal of heat. In refrigeration practice, however, about the only application of this principle is in the case of ammonia absorbed by water and separated again by a process of distillation in the cycle of an absorption plant.

In the absorption system the expanded ammonia gas is collected by taking advantage of the chemical affinity of ammonia for water. Cold water at 50° Fahrenheit will absorb 350 to 400 times its own volume of ammonia gas, making a solution that is known to commerce as aqua-ammonia.

In absorbing this ammonia gas by the water 925.7 heat units are given up for each pound of ammonia gas absorbed under atmospheric pressure, and since action and reaction are equal but opposite, and heat is given up when ammonia gas is absorbed, heat will be absorbed when the gas is again liberated from the water. The quantity of heat necessary to liberate one pound of anhydrous ammonia gas is 925.7 B. T. U., which is the same amount of heat that is given out by the solution when the gas is being absorbed. The solubilities of different gases in water at atmospheric pressure can be found in Table V.

TABLE V

SOLUBILITY OF GASES IN WATER AT ATMOSPHERIC PRESSURE

1 Vol. Water Dissolves Vols. Gas	32° Fahr.	39.2° Fahr.	50° Fahr.	60° Fahr.	70° Fahr.
Air	.0247	.0224	.0195	.0179	.0171
Ammonia	1049.6	941.9	812.8	727.2	654.0
Carbon dioxide	1.7987	1.5126	1.1847	1.0020	.9014
Sulphur dioxide	79.789	69.828	56.647	47.276	39.374
Marsh gas	.0545	.0499	.0437	.0391	.0350
Nitrogen	.0204	.0184	.0161	.0148	.0140
Hydrogen	.0193	.0193	.0191	.0193	.0193
Oxygen	.0411	.0372	.0325	.0299	.0284

Intense cold can be produced by the mixture of various chemicals to form chemical combinations and solutions. In Table VI will be found a number of so-called freezing mixtures, in most of which snow or ice are used. Intense cold can be produced, however, without the aid of snow or ice, as may be seen by the combination of sodium sulphate, ammonium nitrate and nitric acid, which will lower the temperature of the mixture 64° Fahrenheit, or from 50° above zero to 14° below zero.

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such a room or stands in an ice house he will experience a feeling of cold, not because the ice radiates cold to his person, but because some of the animal warmth of the body is being abstracted to raise the temperature of the ice or refrigerating coils, in accordance with the well-known and universal law of equilibrium of temperature.

In the transfer of heat nature makes use of three distinct methods, or channels, known respectively as conduction, convection and radiation, each of which is employed in refrigeration and ice-making practice.

Conduction of Heat.—Conduction of heat is the progressive movement of heat through or along a substance without perceptible movement of the molecules. If one end of a poker be held in a fire the other end will become heated by conduction. The conduction of heat plays an important part in refrigeration practice, good conduction being necessary in some cases, as, for instance, for cooling coils, while poor conductors of heat, as will later be explained in detail, are necessary to prevent the loss of heat through the walls of storage buildings, and to prevent loss of heat from the cooling coils where exposed in passing to and from the refrigerating rooms.

Convection of Heat.—Convection of heat is the transfer of heat by movement or circulation of the molecules, of the transferring substance. Fluids and gases, such as water and air, can be heated only by convection, while at the same time they are the only mediums that can heat or cool other substances by convection. Heat, for instance, passes by conduction

and convection to the interior of cold-storage buildings. 'Hot air coming in contact with the cooled walls parts with its excess heat, and this heat passes by conduction to the surface of the walls within. Water, on the other hand, is heated in the boilers and water-distilling apparatus of an ice-making plant by heat applied to the bottom of the vessel. When heat is thus applied to a fluid the particles in contact with the heated vessel expand in bulk; consequently become lighter in weight, rise toward the surface and are replaced by colder and denser particles flowing in from the sides.

Convection is made use of in the manufacture of ice, by the can method, to insure an equal temperature of the brine throughout the tank to insure uniform freezing. Brine agitators and circulating pumps are used to keep the brine in motion, circulating throughout all parts of the tank, so that even the most remote corners will be cold as the brine in other parts of the tank.

Circulation of fluids through pipes to transfer temperature or heat from one point to another is akin to convection and may properly be considered as such. Steam or hot water conveyed through piping to a radiator is a familiar example of such a method, while withdrawing heat from a cold storage room by means of refrigerating coils is a similar example common to refrigeration practice.

Convection of air currents is also used in refrigeration work for cooling storage rooms where the humidity must be kept very low, or where occasional changes of air are necessary, so that the air in the rooms will be always fresh and pure.

Radiation of Heat.—Radiation of heat is the transmission of heat through space from a warm body to one of lower temperature. For example, the earth is warmed by radiation of heat from the sun. Radiant heat does not heat the air through which it passes; it travels direct and in straight lines until intercepted when it is reflected or absorbed by the intercepting body. Absorption and radiation are equal and opposite. The better the absorptive power of a substance the better radiating material it would make. Lampblack, which has absorbing and radiating powers rated at 100, is taken as the standard of comparison. In proportion as the reflecting power of a substance diminishes, its powers to absorb and radiate heat increase.

The absorbing, radiating and reflecting capacities of various substances are given in Table VII.

TABLE VII

ABSORPTION AND RADIATION OF SUBSTANCES

Substance	Powers	
	Radiating and Absorbing	Reflecting
Lampblack	100	0
Water	100	0
Carbonate of lead	100	0
Writing paper	98	2
Marble	93 to 98	7 to 2
Isinglass	91	9
Ordinary glass	90	10
Ice	85	15
Cast iron	25	75
Wrought iron, polished	23	77
Steel, polished	17	83
Tin	15	85
Brass, cast, dead polished	11	89
Brass, hammered, dead polished	9	91
Brass, cast, bright polished	7	93
Brass, hammered, bright polished	7	93
Copper, varnished	14	86
Copper, deposited as iron	7	93
Copper, hammered or cast	7	93

The significance of the values given in the foregoing table will better be realized when the radiant action which takes place in a refrigeration room is considered. The refrigerating fluid passing through the pipe coils keeps the pipes lowered to such a temperature that they are covered with frost. When a beef, for instance, is placed in the room a transfer of heat by radiation immediately takes place from the beef to the refrigerating coils, and the rate of this transmission of heat would depend somewhat on the material of the pipe coils. In ordinary ammonia refrigeration practice the corrosive effect of the refrigerants used restricts the choice of pipe to that of iron, but if tin, copper or brass were suitable otherwise, they would absorb less heat on account of the lower absorptive capacity of the material. On the other hand, the transmission of heat by conduction through the walls of the pipe to the refrigerating fluid within would be so much greater in the case of copper over cast or wrought iron that it would more than offset the lack of absorption of the material itself.

In coating the pipes to keep them from rusting a mixture of carbonate of lead (ordinary white lead is a carbonate of lead), colored black with lampblack, would not decrease the absorptive capacity of the coils, and, on account of the high absorptive capacities of carbonate of lead and lampblack, 100 each, coils painted with them might actually be improved in absorptive capacity.

Mechanical Equivalent of Heat.—The mechanical theory of heat regards heat as a mode of motion, and investigation has shown that there exists a definite

relation between those two forms of energy, which is known as the *mechanical equivalent of heat*, or Joule's equivalent. That is, if, as in the experiments of Joule, a certain known amount of mechanical energy be expended, as, for instance, by the falling of a weight to operate paddles in a vessel of water, the increase in temperature of the water, due to agitation by the paddles, will always be found proportional to the work done. This relation or proportion is expressed by the amount of work necessary to raise the temperature of one pound of water at 62° Farenheit through one degree at atmospheric pressure, or, in other words, impart one British Thermal Unit to the water. The heat necessary to raise the temperature of one pound of water from 62° to 63° temperature was found by Joule to be able to perform work equal to the raising of 772 pounds one foot in height. The latest experimental determination of Rowland shows that the exact value is somewhat higher than 772, and 778 is the value now usually accepted as the correct mechanical equivalent.

The application of the mechanical equivalent of heat to refrigeration practice will be pointed out later in explaining how to determine the mechanical capacity or power required to abstract a given quantity of heat from stored products, or water that is to be converted into ice.

Work.—Work is the overcoming of resistance encountered along the path of motion. Mere motion itself is not necessarily work, but when a force produces acceleration, or when it maintains motion unchanged in opposition to resistance, it does work.

Work, like all energy, can be measured by certain standards. The unit of work, or the measure of work, is the foot pound, which is the amount of effort or work required to raise one pound one foot vertically. For example, a man carrying a weight up a flight of stairs does an amount of work equal to his own weight, plus the weight of his load, plus the frictional resistance reduced to an equivalent weight, times the vertical height of the stairs. Thus, if the man weighs 200 pounds and carries a load of 100 pounds against a frictional resistance equal to 20 pounds up a vertical height of stairs of 20 feet, the work done would be equal to $(200 + 100 + 20) \times 20 = 6{,}400$ foot pounds.

The work of a machine can be determined in the same way; a pump, for instance, raising a certain weight of water a known height against the frictional resistance of the piping and overcoming the frictional resistance of its own parts, does an amount of work which can be reduced to foot pounds. The efforts of refrigerating machines and steam boilers, on the other hand, which perform the work more by the applying or abstracting of heat units than by the raising of weights, can have the mechanical equivalents of heat converted into foot pounds whenever necessary to do so.

In all cases the amount of work performed can be found by the following rule:

RULE.—Work always equals the force, or resistance overcome, multiplied by the distance through which it acts. If a weight be raised, the weight in pounds multiplied by the vertical height in feet of the lift equals the work in foot pounds.

Power.—Time is an element to be considered in judging the capacity of a machine. Work itself is independent of time, no consideration being given to whether it takes one minute or one year to perform it, but, in order to compare with a common standard the work done by different machines, time must be considered.

If one machine performs a certain amount of work in 10 minutes and another machine does exactly the same amount of work in 5 minutes, the second machine can do twice as much work as the first machine in the same time.

The horsepower is the common standard to which all work is reduced. A horsepower is the work necessary to raise 33,000 pounds 1 foot vertically in one minute; or to raise vertically 1 pound 33,000 feet in one minute; or 11,000 pounds 3 feet in one minute; or 3 pounds 11,000 feet in one minute; or any other combination that will, when multiplied together, give 33,000 foot pounds in one minute.

Thus, the work done in raising 132,000 pounds in one-quarter minute is a horsepower, for 132,000 × .25 = 33,000 foot pounds, and raising 110 pounds vertically 5 feet in one second is a horse-power, for since in one minute there are 60 seconds, 110 × 5 × 60 = 33,000 foot pounds in one minute.

The abbreviation for horsepower is H. P.

Kinetic Energy.—Energy may be considered as the ability of an agent to do work. Work cannot be done without motion and the work that a moving body is capable of doing in being brought to rest is known as

the kinetic energy of the body. The distinction between kinetic energy and work, then, is this: a body moving with a certain velocity and meeting with no resistance is not doing any work, but has a certain amount of kinetic energy, capable of doing work, stored up in it, the amount depending on the velocity and mass of the body.

The kinetic energy, then, means the actual energy of a body in motion. The work that a moving body is capable of doing in being brought to rest is of exactly the same amount as the kinetic energy developed by it in falling in a vaccum through a height sufficient to give it the same velocity.

If a weight be raised a certain height a certain amount of work is done equal to the product of the weight and the vertical height. If the weight now be allowed to fall it will do the same amount of work in foot pounds that was required to raise the weight to the height from which it fell, and this ability to do work is the kinetic energy of the weight.

The kinetic energy of a body can be found by the following rule:

RULE.—The kinetic energy of a body in foot pounds equals its weight in pounds, multiplied by the square of its velocity in feet per second, and divided by the constant 64.32. Expressed as a formula:

$$K = \frac{WV^2}{64.32}$$

In which:

K = kinetic energy.

W = weight in pounds.

V = velocity in feet per second.

EXAMPLE.—What is the kinetic energy of a ball weighing 50 pounds when traveling at a velocity of 100 feet per second?

SOLUTION.—Substituting the given values in the formula:

$$\text{Kinetic energy} = \frac{WV^2}{64.32} = \frac{50 \times 100^2}{64.32} = 7{,}773.63$$

foot pounds. (Answer.)

It requires the same amount of work or energy to stop a body in motion within a certain time, as it does to give it that velocity in the same length of time.

Potential Energy.—Potential energy is latent energy, or energy at rest. It is the energy which a body at rest is capable of giving out under certain conditions. A stone on the edge of a precipice has potential energy. If the stone should be dislodged so as to fall to the ground below, during the fall its potential energy would be changing to kinetic energy, so that at the instant it struck the ground its potential energy would be wholly converted into kinetic energy. Further, at a point equal to one-half the height of the fall the potential and kinetic energies would be equal, At the end of the first quarter the potential energy would be three-fourths and the kinetic energy one-fourth; at the end of the third quarter the potential energy would be only one-fourth and the kinetic energy three-fourths.

A pound of coal or a gallon of oil has a certain amount of potential energy. When the fuel is burned under a boiler the potential energy is liberated and changed to kinetic energy in the form of heat. The

kinetic energy of the heat changes water to steam, which in turn has a certain amount of potential energy. The steam, acting on the steam piston of a compressor, causes it to move through a certain space or length of stroke, compressing ammonia in the cylinder, thus overcoming a resistance, changing the potential energy of the steam into kinetic energy and thus doing work.

Potential energy, then, is the energy stored within a body that may be liberated and produce motion, thus generating kinetic energy and doing work, and this potential energy may be in the form of weight or mass which can be set in motion, or heat which can be liberated from fuel, gathered from the rays of the sun or obtained by other means.

Conservation of Energy.—In the economy of nature nothing is destroyed. Energy and matter might seem to disappear or vanish, but they have not been destroyed, they have only changed their forms. If a clock be put in motion the potential energy of the spring is changed to kinetic energy of motion, which turns the wheels, thus producing friction. The friction produces heat, which dissipates into the surrounding air, but still the energy is not destroyed; it merely exists in another form. The potential energy of coal and mineral oil was received from the sun in the form of heat, light and actinic rays, ages ago, and has laid dormant ever since.

PNEUMATICS
PROPERTIES OF GASES

NATURE of Gases.—In speaking of gases, only those so-called permanent gases will be understood which are in a gaseous state at ordinary temperatures and at atmospheric pressure. If heated to a sufficiently high temperature in a vacuum almost everything in existence, whether liquid or solid, can be converted into a gas; and, conversely, every known gas, if subjected to sufficient pressure and low enough temperatures, can be converted successively into a liquid and a solid. For the benefit of the subject under consideration, then, it may be considered that there is no permanent gas; that what we consider gases are like steam, the gaseous form of some denser liquid, and that the gaseous state at atmospheric pressure and ordinary temperatures is simply due to a lower boiling point than water, consequently a lower vaporizing point than steam. That is particularly true of anhydrous ammonia, the refrigerant most extensively used in ice making and mechanical refrigeration.

At ordinary temperatures and atmospheric pressures or less, anhydrous ammonia is in a gaseous state. When, however, it is subjected to a great pressure or low temperature, or a combination of both, the ammonia is reduced to a liquid state.

The foregoing properties, together with numerous others which will shortly be explained, should be thoroughly understood, as they enter very largely into refrigeration practice. The compression and expansion of air, compression, liquification and subsequent expansion of anhydrous ammonia, carbon dioxide, sulphur dioxide and other refrigerants, and the effects produced thereby, form the principal part of ice making and refrigeration.

Pressure of Gases.—In refrigeration practice there are two pressures which must be considered, for both of them enter largely into refrigeration calculations. These two pressures are *absolute pressure* and *gauge pressure.* To understand the difference between gauge pressure and absolute pressure it must be remembered that the air presses upon the surface of the earth at sea level with an intensity, or weight, of 14.7 pounds per square inch, and pressure gauges intended to record ordinary pressures are calibrated to indicate not from the zero of pressure, but starting at the atmospheric pressure of 14.7 pounds. If, therefore, a pressure gauge registered 1 pound pressure, that would be 1 pound gauge pressure above atmospheric pressure. As a matter of fact, however, as everything is subjected to atmospheric pressure, when the gauge registers 1 pound pressure, the real pressure, above zero is 1 + 14.7 the atmospheric pres-

sure, or 15.7 *absolute pressure.* Absolute pressure, then, is the gauge pressure plus 14.7 pounds per square inch, and this distinction must be clear to the mind and not confused with *absolute zero,* explained in a preceding paragraph. Absolute pressure and absolute zero are both extensively used in refrigeration calculations.

The pressure of a gas, like the pressure of water, is transmitted in all directions, pressing upward and sidewise with an intensity equal to that with which it presses downward. A striking property of all gases is their extreme expansibility. If air or other gas in a tank be exhausted of all but the very smallest quantity possible, that small quantity will expand and fill the vessel. If that quantity be still further diminished it will still expand and fill the vessel. Ordinary pressure gauges, such as are used for indicating the pressure of steam and water, are used, likewise, for indicating the pressure of confined air, under pressure, and for other gases except ammonia. For ammonia gas, gauges of steel must be used, as the ammonia would destroy brass, copper or bronze parts. Barometers are used for indicating the pressure of free air—that is, ordinary atmospheric air—which varies in pressure according to the altitude.

Vacuum.—Ordinarily speaking a vacuum is a space devoid of matter—solid, liquid or gaseous. In speaking of a vacuum in refrigeration practice the degree of rarification of gas in a tank receiver or system of piping is understood. As was previously pointed out, the earth is enveloped in a sea of air, which bears down with an intensity of 14.7 pounds per square inch. If, now, a tank or system of piping

be made air tight, and the air within the tank or system partly pumped out, there would be less pressure inside the tank or system than there would be outside, and this condition would be known as a *partial vacuum.* If *all* the air were withdrawn from the tank or system there would be an *absolute vacuum* within, but an absolute vacuum is impossible to produce. At all events, for practical purposes, a partial vacuum is all that is necessary to be considered. As the pressure of the atmosphere is only 14.7 pounds per square inch and *all* of that pressure cannot be removed from the container, it follows, as a natural result, that a greater vacuum than 14.7 pounds cannot be obtained. Indeed, seldom will a greater vacuum than what would be considered 9 pounds absolute be required for ammonia systems, although for sulphur dioxide and sulphate ether vacuums as low as 5 and 1.30 pounds absolute might be required.

Vacuum gauges are generally used to indicate the degree of vacuum within a tank or piping system. Sometimes, however, the vacuum is expressed as so many inches of mercury. To find in pounds per square inch the degree of vacuum it is only necessary to deduct the inches of mercury given or stated from 30, and multiply by .49.

This will be better understood by remembering that the atmosphere will balance a column of mercury 30 inches high, in a perfect vacuum, consequently when there is only a partial vacuum it will balance a column of mercury 30 inches in height, less the amount of the partial vacuum. For instance, if the height of mercury in the column is 24 inches the pressure in the vessel is 30 — 24 = 6 inches of mercury.

In practice it is generally necessary to reduce inches of mercury to pounds per square inch, as that is the unit of measurement used for other pressures above vacuum. This is a simple matter, for a column of mercury 30 inches high will balance a column of air weighing 14.7 pounds per square inch, therefore 1 inch of mercury will balance a column of air weighing 1–30 of 14.7 pounds per square inch, or .49 pounds per square inch.

RULE.—When the atmospheric pressure and the pressure due to the weight of a column of mercury are known the amount of vacuum is that due to their difference and can be converted into pounds per square inch by multiplying by .49, which is the weight of 1 inch of mercury.

Expressed as a formula:

$$(C - c) = .49$$

In which:

C = pressure of atmosphere which can be assumed, 30 inches of mercury at ordinary elevations.

c = number of inches vacuum indicated.

.49 = pressure per square inch of 1 inch of mercury.

EXAMPLE.—A mercury column shows a vacuum of 24 inches in a tank. What is the absolute pressure in the condenser?

SOLUTION.—Substituting the values given in the formula:

$30 - 24 = 6 \times .49 = 2.94$ pounds absolute. (Answer.)

Weight of Gases.—Gases, contrary to general belief, possess the property of weight, which varies with the temperature and pressure of the gas. Air is the most familiar example we have of a gas, and occupies the same place toward other gases as water does to other fluids. The weight of dry air at 32° Fahrenheit and atmospheric pressure of 14.7 pounds to the square inch, is .0807 pounds per cubic foot; consequently, one pound of air would equal 12.4 cubic feet. The weight of gases used in refrigeration practice are important, as they enter largely into the calculations of the capacities of refrigeration and ice-making machines. Their weights, therefore, under different conditions of pressure and temperature, will be given later in tables of properties of different refrigerants.

Specific Heat of Gases.—The specific heat of a gas and fluid is an important property of mechanical refrigeration. It must be remembered that heat is withdrawn from the various compartments by the circulation of a gas or liquid in pipes through the compartments, to absorb heat from the stored products and deliver up that absorbed heat to the cooling water which circulates or flows over the condenser, and circulates around the cylinders of the compresser. If the gas or liquid possesses a high specific heat value, less of it will have to be circulated to carry off the heat and chill the temperature of the storage rooms than if a medium of lower specific heat value were used. The specific heat of a gas may be measured in two ways. First, at constant pressure but varying volume; second, with the gas at constant volume but varying pressure.

The specific heats of various gases, both at constant pressure and at constant volume, can be found in Table VIII.

TABLE VIII

SPECIFIC HEAT OF GASES

Kind of Gas	Specific Heat at		Ratio, Value of K in Formula for Adjustable Compression
	Constant Pressure	Constant Volume	
Air	.23751	.16902	1.405
Oxygen	.21751	.15507	1.402
Nitrogen	.24380	.17273	1.41
Hydrogen	3.40900	2.41326	1.411
Superheated steam	.48050	.34600	1.388
Carbon monoxide	.24790	.17580	1.41
Carbon dioxide	.21700	.15350	1.41
Anhydrous ammonia	.50800	.39130	1.3
Sulphur dioxide	.15530	.12460	1.246

The specific heat of *liquid ammonia* is not definitely known, the values given by different authorities varying from less than 1 to 1.228. In this work the value of 1 will be used (see Table IV), as that was the value adopted for refrigeration calculations by a committee of the American Society of Mechanical Engineers appointed to suggest a standard tonnage basis for refrigeration.

In the last column of the table the relation between the specific heats of the gases at constant pressure and constant volume are given. These relations are expressed as ratios, and are obtained by dividing the specific heats at constant pressures by the specific heats at constant volumes.

The specific heat of a gas is the ratio between the quantity of heat, in heat units, necessary to raise the temperature of one pound of gas through one degree of temperature and the quantity of heat required to warm an equal weight of water 1°.

Compressibility of Gas.—All permanent gases behave the same when subjected to pressure and are condensed or expanded certain definite amounts for every pound of pressure applied or withdrawn. The law governing the compressibility and expansibility of gases is known as Mariotte's Law and is as follows:

Mariotte's Law.—*The temperature remaining the same the volume of a given quantity of gas varies inversely as the absolute pressure.*

It will be noticed that in this law it is the absolute pressure, not the gauge pressure, that is considered.

Interpreted or explained, Mariotte's Law means that if the pressure on a gas contained in a vessel be increased to two atmospheric pressures, which would be 14.7 gauge pressure, or 29.4 absolute pressure, the gas will be compressed to one-half its original volume, provided the *temperature* of the gas remained unchanged. In this respect it must be remembered that the very act of compressing the gas would raise its temperature, so that to remain the same throughout the operation some heat would have to be withdrawn. Assuming, therefore, that the temperature remains the same, if the pressure be increased to three atmospheres the air will be compressed one-third its original bulk. Increasing the pressure successively to four, five, six, eight and ten atmospheres would compress the gas successively to one-quarter, one-fifth, one-sixth, one-eighth and one-tenth its original volume.

A law growing out of Mariotte's Law, that the temperature remaining the same the volume of a given quantity of gas varies inversely as the absolute pressure, is known as Boyle's Law, which is as follows:

Boyle's Law.—*The product of the pressure and volume of a portion of gas is constant, so long as the temperature is constant.*

Interpreted, this means that the product of pressure and temperature of a given quantity of gas will be the same if that gas be compressed or expanded to other pressures. For instance, if a tank containing 100 cubic feet of gas be under an absolute pressure of 14.7 pounds the product of the volume 100 and pressure 14.7 pounds would be 1,470. If, now, the pressure on the gas within the tank be increased to 29.4 pounds, according to Mariotte's Law the volume would be compressed to one-half the volume, or 50 cubic feet. The product of pressure and volume then would be $50 \times 29.4 = 1{,}470$, which is the same as the original product of pressure and volume. This law is generally stated in the form of an equation, thus: $PV = P_1V_1$, in which P = pressure in pounds, absolute; V = volume in square feet.

Knowing the original volume and pressure of gas in a tank or cylinder the second volume or second pressure can easily be obtained. The pressure after the first volume has been changed can be found by the following rule:

RULE.—The new pressure of a given volume of gas, after it has been compressed, can be found by dividing the product of the original volume and pressure by the new volume. Expressed as a formula:

$$P_1 = \frac{PV}{V_1}$$

In which:

P = original absolute pressure in pounds per square inch.

P_1 = final absolute pressure in pounds per square inch.

V = original volume in cubic feet.

V_1 = final volume in cubic feet.

EXAMPLE.—If 100 cubic feet of gas in a tank subject to an absolute pressure of 14.7 pounds absolute be compressed until it occupies only 50 cubic feet of space, what will be the final pressure on the gas?

SOLUTION.—Substituting the given values in the formula:

$$P_1 = \frac{PV}{V_1} = \frac{14.7 \times 100}{50} = 29.4$$

pounds pressure absolute. (Answer.)

In like manner, if it be required to determine the volume of gas after a change of pressure, it can be found by the following rule:

RULE.—Divide the product of the original volume and pressure by the new pressure. The result will be the new volume.

Expressed as a formula, in which the letters have the same values:

$$V_1 = \frac{PV}{P_1}$$

EXAMPLE.—If 100 cubic feet of gas in a tank under a pressure of 14.7 pounds, absolute, has its pressure increased to 29.4 pounds absolute, what will be the final volume of the gas?

SOLUTION.—Substituting the given values in the formula:

$$V_1 = \frac{PV}{P_1} = \frac{14.7 \times 100}{29.4} = 50 \text{ cubic feet.}$$

(Answer.)

Isothermal Expansion and Compression.—Isothermal expansion of gas is an expansion in which the temperature of the gas remains unchanged, and isothermal compression of gas is brought about without change of temperature of the gas, so that at the completion of the process, when the gas occupies the new state or volume, its temperature will be the same as when in the original volume it was subjected to the original pressure. All of the changes taking place and the values given in accordance with Mariotte's Law and Boyle's Law are isothermal expansions and contractions and values, for they are assumed to have taken place without change of temperature.

Temperatures of Compression and Expansion.—In order to compress gas isothermally some means must be provided to abstract heat, for when a piston is forced into a cylinder to compress gas confined there the temperature of the gas is raised. This increase of temperature is due to the fact that work is required to compress the air, and the work thus expended appears as heat, raising the temperature of the gas. On the other hand, when a gas is allowed to expand, the expansion of the gas lowers its temperature, and to maintain a uniform temperature heat must be supplied from without. This heat which is

generated by the compression of gas and the corresponding amount of heat lost by the gas when again expanded are taken advantage of in sanitary refrigeration, as will later be explained.

Expansion of Gases.—Charles and Gay Lussac's Law states that when the *pressure* is constant all gases expand alike for the same increase of temperature. For instance, suppose one cubic foot of gas be confined in a cylinder having a movable piston, weighted so that it can move in the cylinder as the gas expands, but always keeping the confined gas under a constant pressure. If, then, the gas in the cylinder be heated 1° Fahrenheit, it will be found that the piston has moved in the cylinder and the gas has expanded a certain amount. If the gas be heated 2° it will be found to have expanded twice as much as when heated 1°. If heated 10° it will be found to have expanded just ten times as much as when heated 1°. Further, this expansion will be found practically the same whether the air is being heated from 32° Fahrenheit to 33° or when heated from 200° to 201° Fahrenheit. Similarly, for temperatures below 32° Fahrenheit, the contraction is in the same proportion for each degree of heat abstracted.

The total amount of this expansion for the 180° of Fahrenheit between 32° and 212° Fahrenheit has been found to be .365 of the original volume, or for each degree .365 ÷ 180, or .00203; or, expressed as a fraction, 1/492 of the volume of air at 32° Fahrenheit. This fraction, 1/492, or decimal, .00203, is known as the *coefficient of expansion of air.*

The foregoing may be summed up in the following law of Gay Lussac:

LAW.—*If the pressure of a gas remains comstant the increase of volume per degree rise in temperature will be 1/492 of the volume at 32° Fahrenheit.*

From this it follows that when a gas is heated or cooled at absolute temperature the volume will be directly proportional to the absolute temperatures.

The law of Gay Lussacs can be supplemented by two others, as follows:

LAW I.—All gases have practically the same coefficients of expansion at constant pressure as air, that is, 1/492.

LAW II.—This coefficient is the same whatever the pressure to which the gas may be subjected.

These two laws are not absolutely exact, since they express the expansion and compression of gases approximately only. They are close enough, however, for all practical purposes of refrigeration, for unless the gas is compressed to a very high pressure or cooled to almost the point of liquefaction, the laws will be found to be very nearly true.

The fact that all gases have practically the same coefficient of expansion simplifies the subject, as the one coefficient can be used for any and all of the gases used in refrigeration practice.

Adiabatic Expansion and Compression.—The word adiabatic means without transference of heat, and adiabatic expansion or compression of a gas means that the gas is expanded or compressed without transmission of heat to or from the gas. This would be the case were the compression or expansion to take place

in an absolutely non-conducting cylinder, which would not conduct heat nor permit the escape of heat by radiation.

When a gas is compressed adiabatically the heat that is added to it by the work of compression cannot escape; consequently the gas will have a higher temperature than if it were compressed isothermally. That being true, and the heat added to a given weight of a perfect gas under constant pressure varying directly as the absolute temperature, it follows that the product of pressure and volume at one stage of the compression will not equal the pressure and volume ($PV = P_1V_1$) at another stage, as is the case of isothermal expansion and contraction. On the contrary, the change of state or condition of adiabatic compression and expansion is expressed by the equation pressure times the kth power of the volume equals a constant. That is:

$$PV^k = \text{a constant}$$

In which:

P = absolute pressure.

V = volume in cubic feet.

k = the ratio of specific heat at constant pressure to that at constant volume. The value of k, for different gases used in refrigeration, can be found in the last column of Table VIII.

Liquefaction of Gases.—Most gases, by a combination of high pressure and low temperature, can be condensed to a liquid form. This principle is made use of in refrigeration practice and in compression refrigeration systems the gas passes successively through a cycle of compression, liquefaction and ex-

pansion. In ammonia compression systems the ammonia is compressed, conducted into pipe coils over which water flows, where it is cooled to the point of liquefaction. The liquid ammonia is then allowed to evaporate at a lower pressure in another system of coils, where it absorbs from the coils themselves and from near-by objects the heat required for evaporation, thereby lowering the temperature of those substances.

There are several other liquids which produce a cooling effect, similar to that of anhydrous ammonia, when allowed to vaporize at low temperature; several of them which are used in refrigeration practice may be found in Table IX.

The value of a vaporizing liquid in producing cold depends to a large extent on its latent heat and vaporizing point. In order to be of value as a refrigerant the liquid must have a high latent heat value and a comparatively low vaporizing point.

TABLE IX

BOILING POINTS OF REFRIGERANTS AT DIFFERENT PRESSURES

Temperature of Boiling Point Deg. F.	Absolute Pressure of Vapor in Pounds per Sq. In.			
	Sulphur Dioxide	Anhydrous Ammonia	Carbon Dioxide	Pectet's Fluid
—40	....	10.69	....	....
—31	....	13.75	....	....
—22	5.56	17.50	210	....
—13	7.23	22.08	249	....
—4	9.27	27.59	292	13.5
5	11.76	34.16	342	16.2
14	14.75	41.98	396	19.3
23	18.31	51.18	457	22.9
32	22.53	61.95	525	26.9
41	27.48	74.48	599	31.2
50	33.26	88.96	680	36.2
59	39.93	105.60	768	41.7
68	47.62	124.62	864	48.1
77	56.39	146.26	968	55.6
86	66.37	170.75	1,080	64.1
95	77.64	198.35	....	73.2
104	90.32	....	....	82.9

It will be seen by the table that anhydrous ammonia will vaporize at the exceedingly low temperature of 40° below zero, and at the low pressure of 10.69 pounds absolute, per square inch. Sulphur dioxide, the next in order, vaporizes at a temperature of 22° below zero, and 5.56 pounds pressure, absolute. Carbon dioxide, likewise boils at a temperature of 22° below zero, but at the extremely high pressure of 210 pounds per square inch, while Pectet's fluid requires a pressure of 13.5 pounds, absolute, and a temperature of 4° below zero.

REFRIGERANTS

CHAPTER IV

PROPERTIES OF REFRIGERANTS
ANHYDROUS AMMONIA

ANHYDROUS means without water, consequently anhydrous ammonia, whether in the gaseous or liquid state, contains no water, but is a pure gas made liquid by pressure and low temperature. The term anhydrous is used to distinguish pure ammonia from the solution of ammonia and water of commerce, commonly known as *aqua ammonia.*

Ammonia is composed of one part nitrogen and three parts hydrogen. It can be obtained from sal-ammoniac, or from the nitrogenous constituents of plants and animals by process of distillation—as a matter of fact, there are very few substances free from it.

At the present time almost all the sal-ammoniac and ammonia liquors are prepared from ammoniacal liquid, a by-product obtained in the manufacture of coal gas.

Pure ammonia liquid is colorless, having a peculiar alkaline odor and caustic taste. It turns red litmus paper blue. Its boiling point depends on its purity, and is about 28 6/10° below zero at atmospheric pressure. Compared with water its weight, or specific gravity at 32° Fahrenheit, is about five-eighths of water, or .6364. One cubic foot of liquid ammonia weighs 39.73 pounds, one gallon weighs 5 3/10 pounds, and one pound of the liquid at 32° will occupy 21.017 cubic feet of space when evaporated at atmospheric pressure. The specific heat of ammonia gas, as determined by Regnault (capacity for heat) is .50836. Its latent heat of evaporation, as determined by the highest authorities, is not far from 560 thermal units at 32°, at which temperature one pound of liquid, evaporated under a pressure of 15 pounds per square inch, will occupy 21 cubic feet.

At ordinary temperatures and at atmospheric pressures anhydrous ammonia is a gas, and is reduced to its liquid form only by pressure, reduction of temperature, or both. At a gauge pressure slightly above 15 pounds per square inch ammonia can be liquefied at a temperature of 0° Fahrenheit.

In Table X will be found the properties of saturated ammonia. This table is lacking in some of the data contained in Table XI, but is so much more full and complete as to properties under different temperatures that both tables are reproduced.

The values given in the table are for every degree of temperature from 40° Fahrenheit below zero to 100° above zero, which includes the whole range of temperatures likely to be used in practice.

It might be well to point out here that saturated ammonia means anhydrous ammonia in contact with liquid anhydrous ammonia, and is not to be confused with aqua-ammonia.

For intermediate temperatures the corresponding values of the different properties can be found by interpolation. In addition to covering the whole range of temperature these tables give all the properties of saturated ammonia required to solve problems in refrigeration practice.

Take, by way of explanation, one set of properties. It will be seen by the tables that at a temperature of 10° below zero Fahrenheit the ammonia is under an absolute pressure of 23.80 pounds per square inch, or a gauge pressure of 9.1 pounds per square inch. At that pressure and temperature each pound of ammonia possesses 561.61 heat units, which will be utilized by vaporizing, thereby absorbing heat from surrounding objects, just as steam at the atmospheric pressure in condensing will emit or give up 965.8 heat units. In either case the heat stated is the available energy to perform useful work. In like manner, at the stated pressure and temperature, one pound of vapor would occupy 11.385 cubic feet of space, and each cubic foot of the vapor would weigh .878 pound, while the weight of a cubic foot of the liquid ammonia would be 41.135 pounds.

TABLE X

PROPERTIES OF SATURATED AMMONIA GAS

De Volson Wood and Geo. Davidson

Gauge Pressure Lbs. per Square Inch	Absolute Pressure, Lbs. per Square Inch	Temperature, Degrees Fahr.	Absolute Temperature, Degrees F.	Latent Heat of Evaporation in Thermal Units	Volume of 1 lb. Vapor in Cubic Feet	Weight of 1 Cubic Foot of Vapor in Lbs.	Volume of 1 Lb. of Liquid in Cubic Feet	Weight of 1 Cubic Foot of Liquid in Lbs.
—4.01	10.69	—40	420.66	579.67	24.38	.0410	.0234	42.589
—2.39	12.31	—35	425.66	576.68	21.32	.0469	.0236	42.337
—0.57	14.13	—30	430.66	573.69	18.69	.0535	.0237	42.123
+1.47	16.17	—25	435.66	570.68	16.44	.0608	.0238	41.858
3.75	18.45	—20	440.66	567.67	14.51	.0690	.0240	41.615
6.29	20.99	—15	445.66	564.64	12.83	.0779	.0241	41.374
9.10	23.80	—10	450.66	561.61	11.38	.0878	.0243	41.135
12.22	26.92	—5	455.66	558.56	10.12	.0988	.0244	40.900
15.67	30.37	0	460.66	555.50	9.03	.1107	.0246	40.650
19.46	34.16	+5	465.66	552.43	8.07	.1240	.0247	40.404
23.64	38.34	10	470.66	549.35	7.23	.1383	.0249	40.160
28.24	42.94	15	475.66	546.26	6.49	.1541	.0250	39.920
33.25	47.95	20	280.66	543.15	5.84	.1711	.0252	39.682
38.73	53.43	25	485.66	540.03	5.27	.1897	.0253	39.432
44.72	59.42	30	490.66	536.91	4.76	.2099	.0255	39.200
51.22	65.92	35	495.66	533.78	4.31	.2318	.0256	38,940
58.29	72.99	40	500.66	530.63	3.91	.2554	.0258	38.684
65.96	80.66	45	505.66	527.47	3.56	.2809	.0260	38.461
74.26	88.96	50	510.66	524.30	3.24	.3084	.0261	38.226
83.22	97.92	55	515.66	521.12	2.96	.3380	.0263	37.994

92.89	107.59	60	520.66	517.93	2.70	.3697	.0265	37.736
103.33	118.03	65	525.66	514.73	2.48	.4039	.0266	37.481
114.49	129.19	70	530.66	511.52	2.27	.4401	.0268	37.230
126.52	141.22	75	535.66	508.29	2.09	.4791	.0270	36.995
139.40	154.10	80	540.66	505.05	1.92	.5205	.0272	36.751
153.18	167.88	85	545.66	501.81	1.77	.5649	.0273	36.509
167.92	182.62	90	550.66	498.55	1.64	.6120	.0275	36.258
183.65	198.35	95	555.66	495.29	1.51	.6622	.0277	36.023
200.42	215.12	100	560.66	492.01	1.39	.7153	.0279	35.778
218.28	232.98	105	565.66	488.72	1.289	.7757	.0281	.....
237.27	251.97	110	570.66	485.42	1.203	.8312	.0283	.....
258.7	272.14	115	575.66	482.41	1.121	.8912	.0285	.....
275.79	293.49	120	580.66	478.79	1.041	.9608	.0287	.....
301.46	316.16	125	585.66	475.45	.9699	1.0310	.0289	.....
325.72	340.42	130	590.66	472.11	.9051	1.1048	.0291	.....
350.46	365.16	135	595.66	468.75	.8457	1.1824	.0293	.....
377.52	392.22	140	600.66	465.39	.7910	1.2642	.0295	.....
405.79	420.49	145	605.66	462.01	.7408	1.3497	.0297	.....
435.5	450.20	150	610.66	458.62	.6946	1.4396	.0299	.....
466.84	481.54	155	615.66	455.22	.6511	1.5358	.0302	.....
499.70	514.50	160	620.66	451.81	.6128	1.6318	.0304	.....
534.34	549.04	165	625.66	448.39	.5765	1.7344	.0306	.....

One atmosphere in this table is equal to a pressure of a column of mercury 29.9 inches high.

Specific heat of ammonia gas and vapor at constant pressure..... = 0.508

The same at constant volume..... = 0.3913

Weight of 1 cubic foot liquid ammonia at 32° Fahr..... = 39.108 lbs.

Volume of 1 lb. liquid ammonia at 32° Fahr..... = 0.02557 cu. ft.

Specific heat of liquid ammonia..... = 1.01235 + 0.008378 t, !

TABLE XI

PROPERTIES OF SATURATED AMMONIA

(From Ice and Refrigeration)

Temperature Degrees Fahr.	Absolute Pressure in Pounds per Sq. Inch	Latent Heat of Vaporization in B.T.U. per lb. of Ammonia	Volume of Vapor in Cubic Feet per Pound	Weight of Vapor, Pounds per Cu. Foot	Weight of Liquid, Pounds per Cu. Foot	Temperature Degrees Fahr.	Absolute Pressure in Pounds per Sq. Inch	Latent Heat of Vaporization in B.T.U. per lb. of Ammonia	Volume of Vapor in Cubic Feet per Pound	Weight of Vapor, Pounds per Cu. Foot	Weight of Liquid, Pounds per Cu. Foot
—40	10.69	579.67	24.388	.0410	42.589	+30	59.42	536.91	4.763	.2099	39.200
39	11.00	579.07	23.735	.0421	42.535	31	60.67	536.28	4.668	.2142	39.115
38	11.32	578.47	23.102	.0433	42.483	32	61.95	535.66	4.577	.2185	39.108
37	11.64	577.88	22.488	.0444	42.427	33	63.25	535.03	4.486	.2229	39.047
36	11.98	577.27	21.895	.0457	42.391	34	64.58	534.40	4.400	.2273	39.001
—35	12.31	576.68	21.321	.0469	42.337	+35	65.92	533.78	4.314	.2318	38.940
34	12.66	576.08	20.763	.0482	42.301	36	67.29	533.13	4.234	.2362	38.894
33	13.02	575.48	20.221	.0495	42.265	37	68.68	532.52	4.147	.2413	38.850
32	13.38	574.89	19.708	.0507	42.213	38	70.09	531.89	4.068	.2458	38.789
31	13.75	574.39	19.204	.0521	42.176	39	71.53	531.26	3.989	.2507	38.729
—30	14.13	573.69	18.693	.0535	42.123	+40	72.99	530.63	3.915	.2554	38.684
29	14.53	573.08	18.225	.0549	42.052	41	74.48	529.99	3.839	.2605	38.639
28	14.92	572.48	17.759	.0563	42.000	42	75.99	529.36	3.766	.2655	38.595
27	15.33	571.89	17.307	.0577	41.946	43	77.52	528.73	3.695	.2706	38.550
26	15.75	571.28	16.869	.0593	41.893	44	79.08	528.10	3.627	.2757	38.499
—25	16.17	570.68	16.446	.0608	41.858	+45	80.66	527.47	3.559	.2809	38.461
24	16.61	570.08	16.034	.0624	41.806	46	82.27	526.83	3.493	.2863	38.417
23	17.05	569.48	15.633	.0640	41.754	47	83.90	526.20	3.428	.2917	38.373
22	17.50	568.88	15.252	.0656	41.701	48	85.56	525.57	3.362	.2974	38.328
21	17.97	568.27	14.875	.0672	41.649	49	87.25	524.93	3.303	.3027	38.284
—20	18.45	567.67	14.507	.0689	41.615	+50	88.96	524.30	3.242	.3084	38.226
19	18.94	567.06	14.153	.0706	41.563	51	90.70	523.66	3.182	.3143	38.167
18	19.43	566.43	13.807	.0725	41.511	52	92.46	523.03	3.124	.3201	38.124
17	19.94	565.85	13.475	.0742	41.480	53	94.25	522.39	3.069	.3258	38.080
16	20.46	565.25	13.150	.0760	41.425	54	96.07	521.76	3.012	.3320	38.037
—15	20.99	564.64	12.834	.0779	41.374	+55	97.92	521.12	2.958	.3380	37.994
14	21.53	564.04	12.527	.0798	41.322	56	99.80	520.48	2.905	.3442	37.936
13	22.08	563.43	12.230	.0818	41.271	57	101.70	519.84	2.853	.3505	37.893
12	22.64	562.82	11.939	.0838	41.227	58	103.64	519.20	2.803	.3568	37.845
11	23.22	562.21	11.659	.0858	41.186	59	105.60	518.56	2.753	.3633	37.797

9	25.80	560.55	11.221	.0921	41.034	62	111.66	516.65	2.610	.3851	37.622
8	25.01	560.39	10.860	.0921	41.034	63	113.75	516.01	2.565	.3898	37.579
7	25.64	559.78	10.604	.0943	41.000	64	115.86	515.37	2.520	.3968	37.523
6	26.27	559.17	10.362	.0965	40.950						
−5	26.92	558.56	10.125	.0988	40.900	+65	118.03	514.73	2.476	.4039	37.481
4	27.59	557.94	9.894	.1011	40.849	66	120.18	514.09	2.433	.4110	37.439
3	28.26	557.33	9.669	.1034	40.799	67	122.38	513.45	2.389	.4189	37.383
2	28.95	556.73	9.449	.1058	40.749	68	124.62	512.81	2.351	.4254	37.341
1	29.65	556.11	9.234	.1083	40.700	69	126.89	512.16	2.310	.4329	37.285
0	30.37	555.50	9.028	.1107	40.650	+70	129.19	511.52	2.272	.4401	37.230
+1	31.10	554.80	8.825	.1133	40.601	71	131.54	510.87	2.233	.4479	37.188
2	31.84	554.27	8.630	.1159	40.551	72	133.90	510.22	2.194	.4558	37.133
3	32.60	553.65	8.436	.1186	40.502	73	136.31	509.58	2.153	.4645	37.079
4	33.38	553.04	8.250	.1212	40.453	74	138.74	508.93	2.122	.4712	37.037
+5	34.16	552.43	8.070	.1240	40.404	+75	141.22	508.29	2.087	.4791	36.995
6	34.97	551.81	7.892	.1267	40.355	76	143.72	507.64	2.052	.4873	36.954
7	35.79	551.19	7.717	.1296	40.322	77	146.26	506.99	2.017	.4957	36.900
8	36.63	550.58	7.553	.1324	40.274	78	148.84	506.34	1.995	.5012	36.845
9	37.48	549.96	7.388	.1353	40.225	79	151.45	505.69	1.952	.5123	36.805
+10	38.34	549.35	7.229	.1383	40.160	+80	154.10	505.05	1.921	.5205	36.751
11	39.23	548.73	7.075	.1413	40.112	81	156.78	504.40	1.889	.5294	36.696
12	40.13	548.11	6.924	.1444	40.064	82	159.50	503.75	1.858	.5382	36.657
13	41.04	547.49	6.786	.1474	40.016	83	162.26	503.10	1.827	.5473	36.603
14	41.98	546.88	6.632	.1508	39.968	84	165.05	502.45	1.799	.5558	36.549
+15	42.94	546.26	6.491	.1541	39.920	+85	167.88	501.81	1.770	.5649	36.509
16	43.90	545.63	6.355	.1573	39.872	86	170.75	501.15	1.741	.5744	36.456
17	44.88	545.01	6.222	.1607	39.824	87	173.66	500.50	1.714	.5834	36.407
18	45.89	544.39	6.093	.1641	39.777	88	176.61	499.85	1.687	.5927	36.350
19	46.91	543.77	5.966	.1676	39.729	89	179.59	499.20	1.660	.6024	36.311
+20	47.95	543.15	5.843	.1711	39.682	+90	182.62	498.55	1.634	.6120	36.258
21	49.01	542.53	5.722	.1748	39.635	91	185.69	497.89	1.608	.6219	36.219
22	50.09	541.90	5.605	.1784	39.572	92	188.79	497.24	1.583	.6317	36.166
23	51.18	541.28	5.488	.1822	39.541	93	191.94	496.59	1.558	.6418	36.114
24	52.30	540.66	5.378	.1860	39.479	94	195.13	495.94	1.534	.6518	36.075
+25	53.43	540.03	5.270	.1897	39.432	+95	198.35	495.29	1.510	.6622	36.023
26	54.59	539.41	5.163	.1937	39.386	96	201.62	494.63	1.486	.6729	35.971
27	55.76	538.78	5.058	.1977	39.339	97	204.94	493.97	1.463	.6835	35.919
28	56.96	538.16	4.960	.2016	39.292	98	208.29	493.32	1.442	.6934	35.881
29	58.17	537.53	4.858	.2059	39.246	99	211.68	492.66	1.419	.7047	35.829
						+100	215.12	492.01	1.398	.7153	35.778

Total Heat of Ammonia.—Just as in the steam table there is at atmospheric pressure the heat of the liquid, 180.3 B. T. U., and the heat of vaporization, 965.8 B. T. U., making a total heat of 1146.6 B. T. U., so in the ammonia calculations the total heat and heat of the liquid must be considered. As in the case of steam, the total heat of ammonia is the heat of vaporization plus the heat of the liquid. The heat of the liquid is usually calculated above 32° Fahrenheit, the freezing point of water.

It is the product of the specific heat and the difference between the temperature of the liquid and 32. The specific heat of ammonia, see Table IV, is 1. The heat of a liquid can then be expressed by the formula:

$$H = t - 32$$

In which:

H = heat of the liquid.

t = temperature of liquid.

EXAMPLE.—What is the heat of ammonia vapor at a temperature of 6° Fahrenheit?

SOLUTION.—Temperature, t, = 6; substituting this value in the formula, then $6 - 32 = -26$. (Answer.)

The total heat of ammonia can be calculated by the formula:

$$t = V + H$$

In which:

t = total heat

V = heat of vaporization.

H = heat of liquid.

EXAMPLE.—What is the total heat of 1 pound of saturated ammonia vapor at a temperature of 6° Fahrenheit?

SOLUTION.—Heat of vaporization, V, at 6° Fahrenheit = 551.81; heat of liquid, H, = 6 — 32 = — 26. Substituting those values in the formula, then t = 551.81 + — 26 = 525. 81. (Answer.)

Testing Anhydrous Ammonia for Water.—Ammonia liquid for use in a refrigeration system should be pure, and to make sure that no impure liquid finds its way into the system each flask of ammonia should be tested before using. To test a sample

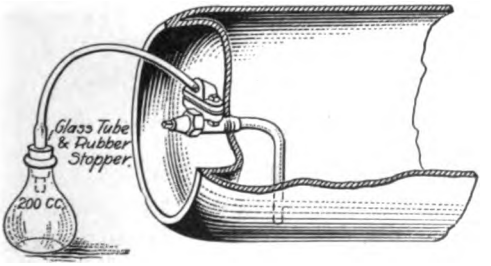


Fig. 1
Drawing Ammonia for Testing

of ammonia for water by evaporation, screw into the ammonia flask, as shown in Fig. 1, a piece of bent one-quarter inch pipe, which will allow a small bottle to be placed so as to receive the discharge from it. This test bottle should be of thin glass, with wide neck, so that ¼-inch pipe may pass readily into it, and of about 200 cubic centimeters capacity. Put the wrench on the valve and tap it gently with a hammer. Fill the bottle about one-third full and throw sample

out in order to purge valve, pipe and bottle. Quickly wipe off the moisture which has accumulated on the pipe, replace the bottle and open valve gently, filling the bottle about half full. This last operation should not occupy more than one minute. Remove the bottle at once and insert in its neck a stopper with a vent hole for the escape of gas. A rubber stopper with a glass tube in it is the best, but a rough wooden stopper, loosely put in, will answer the purpose. Keep the bottle well wrapped up in dry cotton waste or several folds of cloth when drawing off the ammonia or the fingers are liable to become frozen. Procure a piece of solid iron that should weigh not less than 8 or 10 pounds, pour a little water on this and place the bottle on the wet place. The ammonia will at once begin to boil, and in warm weather will soon evaporate. If it shows any residuum pour it out gently, counting the drops carefully. Eighteen drops are about equal to one cubic centimeter and if the sample taken amounted to 100 cubic centimeters. you can readily approximate the percentage of the liquid remaining, which will give you the percentage of impurity of the ammonia. Impurities of any kind, and to the least extent, interfere with the refrigerating efficiency of anhydrous ammonia by retarding its evaporating quality and by preventing its complete evaporation. As the ammonia is used over and over again in the process of refrigeration or ice making, the loss on account of the presence of impurities does not occur only once, but repeats itself on each repetition of the cycle, thereby adding to the cost of operation. Some impurities, furthermore, might help decompose the ammonia and make it explosive.

Great care is necessary in drawing off the sample and very little moisture in the bottle or in the pipe, or a brief exposure to the air, will at once affect it.

Test for Inflammable Gases.—Anhydrous ammonia is not of itself explosive, nor will it burn, but at high temperatures it might become decomposed into nitrogen and hydrogen, and the hydrogen, when mixed with the right proportion of air, will not only burn, but is explosive. Impurities in ammonia, when they exist, might assist the decomposition of the gas and add to the explosiveness of the mixture.

To test ammonia for inflammable gases submerge the open end of the bent quarter-inch pipe, shown in the illustration, in a pail of water, then open the valve slightly, and allow a small quantity of the gas to flow into the water. If inflammable gases are present they will rise in bubbles to the surface of the water, where they may be ignited by the light from a match or candle; the presence of inflammable gas being indicated by its ignition and the absence of the gas by its failing to burn.

Water has a strong affinity for ammonia, which it will absorb immediately, leaving only the air and other gases to rise in the form of bubbles to the surface of the water in the pail.

Test for Boiling Point.—By inserting a special low-temperature standardized chemical thermometer into liquid drawn into the 8-ounce test jar, readings can be obtained through the side of the jar without removing the instrument. Hold the thermometer in such position that only the bulb is immersed. This test will give you the boiling point of ammonia at at-

mospheric pressure, and it is well to know that the state of the barometer affects the temperature of the boiling point. With the barometer at 29.92 inches the boiling point is nearly 28.6-10° below zero. If the ammonia is impure the boiling point will be raised in proportion.

The foregoing are simple tests commonly used to determine the quality of the ordinary article furnished by manufacturers of anhydrous ammonia for use in ice making and refrigerating machines.

Corrosiveness of Ammonia.—Ammonia has no perceptible effect on iron or steel, but rapidly and energetically attacks and destroys copper and brass. For this reason no copper or brass is used in an ammonia refrigerating plant, the valves and other parts which ordinarily are made of brass or copper being made of iron or steel.

TABLE XII

STRENGTH OF AMMONIA LIQUORS

Per Cent. Ammonia by Weight	Specific Gravity	Degrees Beaumè Water 10	Degrees Beaumè Water 0
0	1.000	10.	0
1	.993	11.	1
2	.986	12.	2
4	.979	13.	3
6	.972	14.	4
8	.966	15.	5
10	.960	16.	6
12	.953	17.1	7
14	.945	18.3	8.2
16	.938	19.5	9.2
18	.931	20.7	10.3
20	.925	21.7	11.2
22	.919	22.8	12.3
24	.913	23.9	13.2
26	.907	24.8	14.3
28	.902	25.7	15.2
30	.897	26.6	16.2
32	.892	27.5	17.3
34	.888	28.4	18.2
36	.884	29.3	19.1
38	.880	30.2	20.0

Properties of Aqua Ammonia.—Aqua ammonia, which in the absorption system of refrigeration is generally called ammonia liquor, is a solution of ammonia gas in water.

At atmospheric pressure and 32° Fahrenheit temperature, water will absorb 1,140 times its volume of ammonia gas. Raising the temperature of the liquor, decreasing the pressure, or a combination of both, reduces the capacity of water to absorb ammonia; while cooling the water and increasing the pressure increases the absorptive capacity of the water for ammonia gas. The strength of ammonia liquors or the percentage by weight of gas held in solution together with the corresponding specific gravities and strengths of the solutions, according to Beaumé scale, may be seen in Table XII.

The amount of gas held in solution affects the specific gravity of the liquor, and this difference in specific gravity for different solutions offers a means for measuring the strength of the liquor. The strength of a solution of aqua ammonia is determined by means of an instrument known as a *hydrometer*. A Beaumé hydrometer, which is used for determining the specific gravity of various liquids, is shown in Fig. 2. It consists of a glass tube with a cylinder near one end and a bulb immediately below the cylinder. This bulb is partly filled with mercury and the tube above the cylinder is graduated so that when the instrument is put into a solution it will stand upright and

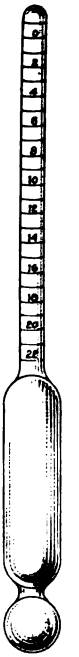


Fig. 2 Hydrometer

sink in the liquid a distance proportional to its strength and specific gravity, and the depth it sinks is indicated by the graduated scale.

There are two graduations used on hydrometer scales. The graduations are the same, but their values differ by 10, which accounts for the two columns devoted to the Beaumé readings in the table.

For liquids lighter than water the instrument is graduated by placing it in a solution of 10 parts salt and 90 parts water and marking the point 0° to which it sinks. The instrument is then placed in distilled water and the distance it sinks marked in like manner 10°. Next the space between the two marks is divided into 10 equal parts, and these divisions are continued to the top of the stem. In the other graduation spoken of the reading for pure water is 0° instead of 10°.

A table is always necessary to determine from a hydrometer reading the exact percentage of gas in the water. For instance, if the hydrometer reading in the 10 scale were 20.7, by consulting Table XII it would be seen that the percentage of gas was 18, and, consequently, there would be 18 parts of gas by weight to 82 parts of water in the solution, with a specific gravity of .931.

Properties of Carbon Dioxide.—Next to anhydrous ammonia carbon dioxide is the most extensively used of the remaining refrigerants. The greatest drawback to the use of this refrigerant is the tremendous pressures necessary to be maintained in the system, the pressures ranging all the way from 200 pounds to 1,000 pounds per square inch.

The properties of saturated carbon dioxide, commonly called carbonic acid gas and carbon anhydride, can be found in Table XIII.

TABLE XIII

PROPERTIES OF SATURATED CARBON DIOXIDE

Temperature of Ebullition in Deg. F.	Absolute Pressure in Lbs. per Sq. In.	Total Heat in B. T. U. above 32° F.	Heat of Liquid from 32° F.	Latent Heat of Vaporisation	Density of Vapor or Weight of 1 Cubic Foot
—30	182	97.50	—41.5	140.	2.
—22	210	98.35	—37.80	136.15	2.321
—20	218	98.50	—36.5	134.	2.45
—13	249	99.14	—32.51	131.65	2.759
—10	206	99.5	—30.9	130.	2.9
—4	292	99.88	—26.91	126.79	3.265
0	312	100.3	—24.	124.	3.5
5	342	100.58	—20.92	121.50	3.853
10	368	100.9	—17.5	118.	4.17
14	396	101.21	—14.49	115.70	4.535
20	434	101.6	—10.	111.	5.
23	457	101.81	— 7.56	109.37	5.331
30	497	102.2	— 1.8	104.	5.9
32	525	102.35	0.60	102.35	6.265
40	588	102.8	7.5	95.	7.
41	599	102.84	8.32	94.52	7.374
50	680	103.24	17.60	85.64	8.708
59	768	103.59	28.22	75.37	10.356
60	772	103.6	29.4	74.	10.6
68	864	103.84	40.86	62.98	12.480
70	889	103.9	44.	60.	13.1
77	968	103.05	57.06	46.89	15.475
80	1000	104.	63.	41.	17.5
86	1080	103.72	84.44	19.28	21.519

Carbon dioxide consists of two atoms of oxygen, and one atom of carbon; it is the same gas as that used in aerating soda water and charging mineral waters, and is the gas that gives the life and sparkle to beer and champagne. Further, it is the chief constituent of the exhalations from the lungs of animals.

The chief characteristics of the gas are absence of odor, neutrality toward material and food products and the fact that it cannot be decomposed under pressure.

Whereas ammonia will attack and destroy brass and copper, carbon dioxide will not injure them. Ammonia is dangerous to animal life and destructive to food products, when brought into contact with them through a leak in the piping system, while carbon dioxide is dangerous to life only when present in quantities greater than 8 per cent., and is beneficial to many food products.

The gas has a specific gravity of 1.529 at atmospheric pressure, and becomes a liquid at 124° below zero, Fahrenheit, or at 156° below the freezing point at that pressure.

Carbon dioxide is artificially produced in pure form by means of combustion of chalks and magnesite or by means of the decomposition of marble with sulphuric or nitric acid.

The critical temperature of carbon dioxide, that is, the temperature above which it cannot be liquefied, is 88.4° Fahrenheit. At a temperature of 32° Fahrenheit a pressure of 525 pounds absolute, per square inch, is required to liquefy the gas.

Carbon dioxide is used in a compression refrigeration system in much the same manner as ammonia is used. The pressures required, however, are much higher, but the temperatures produced are much lower.

Sulphur Dioxide.—In ammonia and carbon dioxide, the two refrigerants commonly used in practice have been described and their properties enumerated. The properties of sulphur dioxide and Pictet's fluid are given to make this work complete, and for

whatever other uses they might be put to—experimentally. So far as their present practical application is concerned they have but little.

Sulphur dioxide is formed by the chemical union of sulphur and oxygen. It is a heavy gas, much heavier than air, having a specific gravity of 2.26 as compared with air at 1.0. The gas is colorless, has a pungent, suffocating odor, resembling the burning sulphur of a common lucifer match. The gas condenses to a thin, colorless liquid when cooled to 14° Fahrenheit. This liquid has a specific gravity of about 1.49, as compared with water, and freezes at a temperature of —105° Fahrenheit.

Sulphur dioxide has practically no injurious effect on the material of which a refrigeration system is constructed, except, perhaps a possible effect on the lubricating oils used.

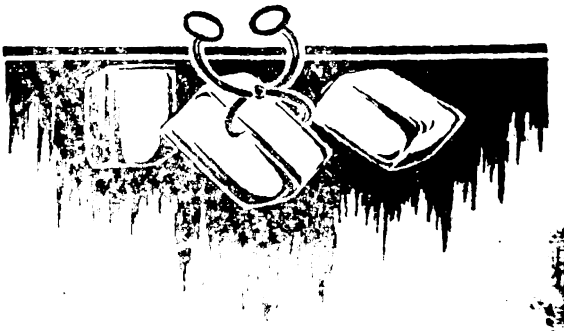
The properties of saturated sulphur dioxide may be found in Table XIV.

TABLE XIV

PROPERTIES OF SATURATED SULPHUR DIOXIDE

Temperature of Ebullition in Deg. F.	Absolute Pressure in Lbs. per Sq. In.	Total Heat above 32°F. in B. T. U. per Lb.	Heat of Liquid from 32° F. in B. T. U. per Lb.	Latent Heat of Vaporization in B. T. U. per Lb.	Density of Vavor, or Weight of 1 Cubic Foot
—40	3.16	155.32	—17.76	172.98	.048
—31	4.23	156.39	—16.55	172.94	.062
—22	5.56	157.55	—15.05	172.60	.079
—13	7.23	158.69	—13.26	171.95	.099
— 4	9.27	159.82	—11.18	171.00	.124
5	11.76	160.93	— 8.82	169.75	.154
14	14.75	162.02	— 6.17	168.19	.190
23	18.31	163.10	— 3.23	166.33	.232
32	22.53	164.16	0.	164.16	.282
41	27.48	165.21	3.52	161.69	.341
50	33.26	166.24	7.32	158.92	.410
59	39.93	167.25	11.41	155.84	.491
68	47.62	168.25	15.79	152.46	.584
77	56.39	169.23	20.45	148.78	.692
86	66.37	170.20	25.41	144.79	.819
95	77.64	171.15	30.65	140.50	.965
104	90.32	172.08	36.18	135.90	1.131

Pictet's Fluid.—Pictet's fluid, named after Professor Pictet, a Swiss physicist, is a mixture of 97 per cent. sulphur dioxide and 3 per cent. carbon dioxide. This mixture gives a boiling point 14° Fahrenheit lower than that of sulphur dioxide, but otherwise possesses no greater value as a refrigerant.



DETAILS OF THE COMPRESSION SYSTEM

CHAPTER VI

THE COMPRESSOR

TYPES and Characteristics of Compressors.—The ammonia compressor is the most important element entering into the make-up of a refrigeration system, and is about the only element that differs in design among the various systems on the market.

The various manufacturers of refrigeration systems will make special compressors to meet unusual conditions, while at the same time they all have stock designs and sizes both horizontal and vertical, and operated by steam, electricity or belt driven. In their main characteristics, all compressors agree. It is in their details that they differ. Ordinarily, compressors are made with as long a stroke as possible to get a comparatively high piston speed with the least number of revolutions, and to cut down the clearance

spaces as much as possible, for with a long stroke and small bore, there is less clearance space than when the piston has a short stroke and large bore. In practice the compressors generally have a stroke of at least double the diameter of the bore of the cylinder, while a stroke of two-and-a-half times the bore is perhaps the best proportion. Good proportions for cylinders is to allow a displacement of 3½ cubic feet of ammonia gas at 25 pounds suction, or back pressure, and 5 cubic feet displacement at 15 pounds suction pressure for single-acting compressors, per ton of capacity, and 4 cubic feet at 25 pounds suction pressure and 5½ cubic feet at 15 pounds suction pressure for double-acting compressors per ton of capacity.

Clearance Spaces.—In a well-designed ammonia compressor the clearnace space when the compressor piston is at the end of its stroke will be reduced to the lowest possible limit. This is absolutely necessary for economic reasons, for whatever gas is left in the cylinder at the end of the stroke will expand as the piston travels back, and will keep a corresponding amount of gas from entering the cylinder, thereby cutting down the capacity of the conpressor. Clearance losses should not exceed 2 or 2½ per cent. the total cylinder volumes. This can be brought about by running the compressor with not more than 1/32 inch clearance between the piston and the cylinder head.

Clearance.—The piston is adjusted for clearance by removing one of the valves and placing a piece of fine wire, soft solder or a strip of sheet lead on the end

of the piston, then turning the fly wheel over until the piston has completed its stroke. The thickness to which the trial piece is flattened will indicate the amount of clearance.

Heat of Cylinders Due to Compression.—In the compression of a gas, as was previously pointed out, the mechanical work of compression is converted into heat, which raises the temperature of the gas. When the temperature of a gas is raised, it increases the pressure to correspond to the temperature, consequently, if the compressor be worked adiabatically, the capacity of the machine will be greatly reduced. Take, for instance, the case of an ammonia compressor operating adiabatically. The first cylinder full of gas is compressed, but in doing so considerable heat is developed, part of which is absorbed by the cast-iron walls of the cylinder, thereby raising its temperature. The next cylinder full of gas flows into a warmer receptacle than the first charge, consequently is heated to a higher temperature and when compressed heats the cylinder to a higher degree than the first cylinder full; and this process keeps on until the cylinder and gas are heated to a temperature, as high as they can be by the process of compression, and the capacity of the compressor cut down greatly. That is what would happen if the gas were compressed adiabatically. As a matter of fact, the gas in a compressor cylinder is not compressed adiabatically, but isothermally. It is far more economical to remove the heat of compression as fast as generated, and keep the temperature of the cylinder comparatively low throughout the compression, than to let the parts

heat up and the gas expand from heat in the cylinder; and in practice this is accomplished by one of three methods known as the dry-compression or water-jacket system; the wet-compression or ammonia-injection system and the oil-injection system.

Dry Compression.—Dry compression is so called because the cylinder and compressed gas are kept comparatively cool without any cooling medium being injected into the cylinder. This is brought about by means of water jackets surrounding the compression cylinders, which are kept full of water. In the case of vertical cylinders, the water jackets are simply tanks surrounding the cylinders, and high enough to cover the top or cylinder heads. The water jackets are open at the top and the water flows off by gravity, the overflow being at the top where the hottest water is. Horizontal compressors are generally water jacketed on the cylinder walls, only the heads being left unjacketed.

In Fig. 6 is shown the interior of a vertical single-acting ammonia compression cylinder. Ammonia gas flows through the inlet valve to the inside of the cylinder, and on the back stroke of the piston flows through the suction valve to the compression side. On the compression stroke of the piston, the gas is forced through the discharge valve into the outlet pipe. On the top of the cylinder are two screw eyes for attaching to block and fall to remove the cylinder head; and where the piston rod passes through the stuffing box is an oil pocket and oil pipe, through which oil is pumped or otherwise forced to keep the packing properly lubricated.

Surrounding the cylinder is the water jacket, between which and the cylinder, water flows to carry off the heat due to compression.

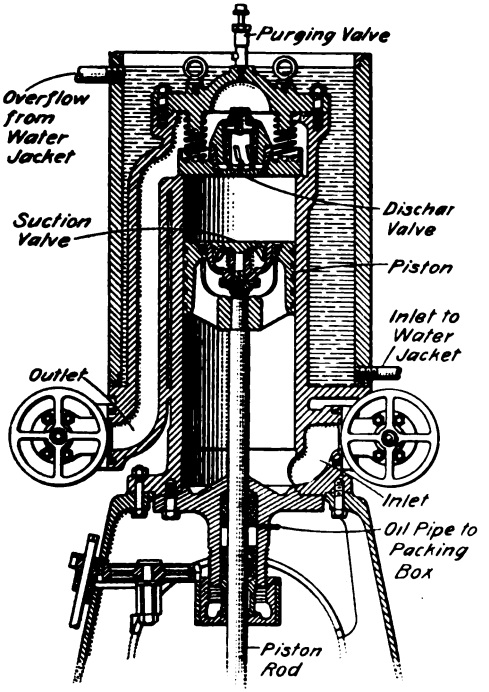


Fig. 6
Water-cooled Compression Cylinder

About 1/5 of a gallon of water per minute is required, per ton of refrigeration effort, for circulation through the water jackets of the compression cylinders. If the water is much above 60° Fahrenheit, a greater allowance will be required. In the compression of the dry ammonia gas, there is at best only an imperfect

transfer of heat through the thick cast-iron cylinder walls to the water in the water jacket, so that the gas is discharged from the cylinder at a much higher temperature than that corresponding to its pressure. This superheating results in raising the temperature of the cylinder walls, cylinder heads, piston rod, valves and other parts to such a degree that the gas entering the cylinder on the suction stroke, and coming in contact with these hot surfaces, increases in volume, thus reducing the capacity of the machine, since a less weight of ammonia enters than would be the case if the gas were maintained at the density at which it comes to the suction conduit.

It is to try and avoid this loss that the wet compression and oil-injection methods are employed.

Wet Compression.—In the wet system of compression a small portion of liquid ammonia is carried into the compression cylinder at the commencement of each compression stroke. This liquid ammonia begins to evaporate immediately, the same as it would in the expansion coils, and, absorbing heat from the ammonia gas raised in temperature by the compression of the piston, keeps the temperature during compression from rising to an excessive degree. The amount of liquid ammonia injected is proportioned to the cooling effect to be produced so it will be just sufficient to keep down excessive heat without cooling the gas too much.

Oil-Injection Compression.—In the oil-injection system of compression, a light parafine oil known as *liquid base* is injected into the compressor just after it has received its charge of cold ammonia gas.

The object of injecting the oil is to seal the piston and piston rods, lubricate the piston and piston rod, and absorb enough of the heat of compression to keep the cylinder and discharge gas from overheating. Oil

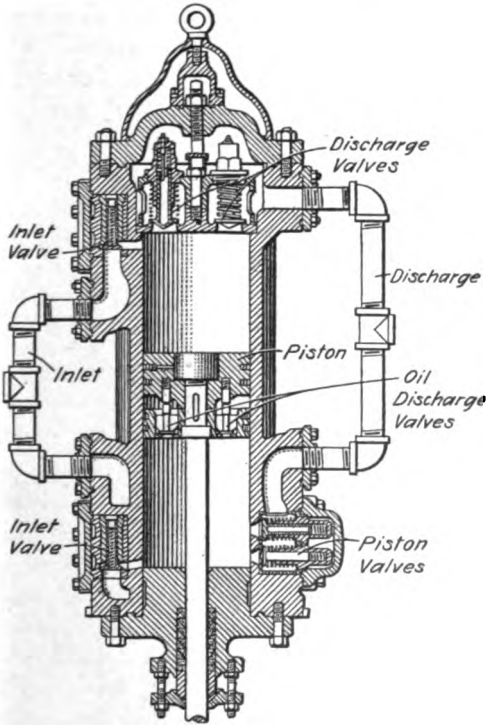


Fig. 7
Oil-Injector Compression Cylinder

is injected in the cylinders by means of a little oil pump, shown attached to the side of the compressor frame in Fig. 5, and operated automatically to inject the right amount of oil at each stroke of the compressor pistons.

The interior of a vertical double-acting oil injection compressor cylinder is shown in Fig. 7. The ammonia gas returning from the expansion coils enters the cylinder through the divided suction line, shown to the left, and the inlet valves, one at the top and the other near the bottom of the cylinder. While the gas on one side of the piston is being discharged, the space on the other side is filling with gas from the suction pipe. The discharge of gas from the lower end of the cylinder takes place simultaneously through the two discharge valves shown at the right-hand side of the illustration, until the parts leading to the valves are covered by the descending piston. Any remaining gas or oil is then discharged through the small piston valves into a cavity within the piston which connects with the upper discharge valve at the right. Oil is injected into the cylinder just before the compression stroke, through a pipe not shown in the illustration.

By-Passes and Cross Connections.—By means of a system of cross connections or by-passes similar to the one shown in Fig. 8, between the main suction and discharge pipes, the engineer in charge is enabled to exhaust the ammonia from any part of the system and temporarily store it in another part until the repairs or examinations have been made. The by-passes are likewise used for exhausting the compressors themselves, before the heads are removed for examination. By means of a system of cross connections in the piping system and the arrangement of pipes and valves shown, it is likewise made possible to reverse the action of the compressor and exhaust the ammonia from the condenser, storing it in the expansion coils.

After the examination or repair of any part, the air may be exhausted therefrom and the charge of ammonia reintroduced without the admixture of air.

By-pass valves are always kept closed while the refrigeration system is in ordinary use and are opened only when occasion requires.

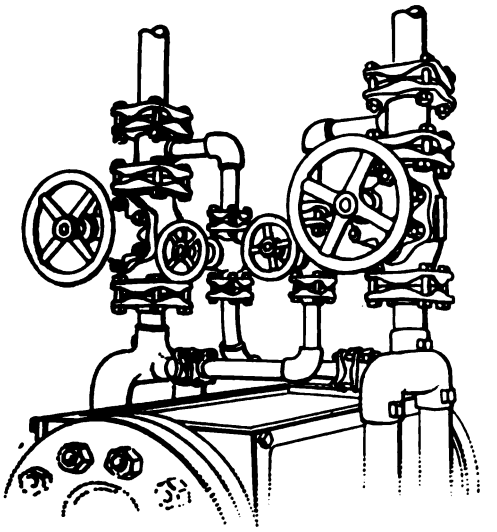


Fig. 8
By-pass on Compression Cylinder

The by-pass shown in the illustration is for a single machine; for a duplex compressor, a double cross connection is necessary to exhaust from both the cylinders at the same time, or so that one compress can be used singly. The principle, however, is the same as for the single compressor, the amount of piping and valves only being greater.

Refrigerating Capacity and Ice-Making Capacity of Compressors.—Much misunderstanding is caused among those not well versed in refrigeration and ice making by the terms refrigerating capacity and ice-making capacity of a compressor. An understanding of these terms will be quite easy, however, if the different functions of a system, ice making and refrigerating, be kept in mind. Previous to the introduction of refrigerating machinery, natural ice was the only means available for reducing the temperature of storage places, such as breweries and meat-packing establishments. Upon the introduction of refrigerating machinery it was at first used almost exclusively to take the place of ice in such establishments, and if a refrigerating machine affected the same amount of cooling in twenty-four hours as was accomplished by the melting of 100 tons of ice in the same time, the machine was rated as a 100 ton machine. The refrigerating capacity takes into account only the heat absorbed in the conversion of ice into water at 32° Fahrenheit, or, what would be the equivalent, the freezing of water at 32° Fahrenheit into ice. In ice making, however, the water from which the ice is to be made must be cooled from its ordinary temperature to 32° Fahrenheit as well as frozen into ice. Besides, the average temperature of the ice when it leaves the freezing tank is much below 32°, and this imposes still more extra work on the refrigerating capacity of the ice machine. Then there are losses from the absorption of heat through the walls of the freezing tanks, from harvesting and other causes. Take for instance a 100 ton refrigerating machine rated at 25 pounds back pressure. If operated at 15 pounds (which would be necessary in

ice making), with other conditions unchanged, the refrigerating capacity would be reduced to 75 tons. This is because the refrigerating capacity of a compressor depends on the number of pounds of ammonia gas which the compressor can take from the refrigerator coils and discharge into the condenser in 24 hours, and the weight of ammonia handled varies directly as the absolute back pressure. As the temperatures required for ice making are much below 32° Fahrenheit, varying between 15° and 0° Fahrenheit, it is necessary to operate the compressor under a back pressure much below 25 pounds—say, from 15 to 20 pounds—while in refrigeration, temperatures are generally above freezing, which allows a back pressure in the suction pipe of 25 pounds. This lower back pressure in ice making consequently reduces the actual refrigerating capacity of the compressor to much below its rated capacity.

Tonnage Capacity of Compressors.—The question as to what shall constitute the unit of refrigeration as applied to the actual operating capacity of the refrigerating compressor, and how this is to be accurately determined or measured, has been the subject of much discussion during the past several years among those interested in this class of machinery. Up to the present time, however, no definite unit has been absolutely adopted, though it is conceded by the trade that the refrigerating capacity of a compressor depends upon the number of pounds of gas it will handle in a given unit of time. The weight of ammonia gas handled depends upon the efficiency of the compressor and particularly upon the suction pressure, or the pressure at which the gas is delivered into the compressor.

TABLE XV

NUMBER OF CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES, TO PRODUCE ONE TON OF REFRIGERATION IN TWENTY-FOUR HOURS

Temperature of Gas in Degrees Fahr.	Corresponding Suction Pressure, Lbs. per Sq. In.	Temperature of the Gas in Degrees Fahr. 65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), lbs. per sq. in. 103	115	127	139	153	168	184	200	218
		Cubic feet of gas that must be pumped per minute*								
	G. Pres.									
—27°	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20°	4	5.84	5.9	5.96	6.03	6.09	6.23	6.16	6.30	6.43
—15°	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10°	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
— 5°	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0°	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5°	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10°	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15°	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20°	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25°	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30°	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35°	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

*Add 20 per cent. to these values to get the amounts required in practice.

TABLE XVI

REFRIGERATION EFFECT OF ONE CUBIC FOOT OF AMMONIA GAS AT DIFFERENT CONDENSER AND SUCTION (BACK) PRESSURES IN B. T. UNITS

Temperature of Gas in Degrees Fahr.	Corresponding Suction Pressure, Lbs. per Sq. In.	Temperature of the Liquid in Degrees Fahr. 65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), lbs. per sq. in. 103	115	127	139	153	168	184	200	218
		Refrigerating effect of 1 cubic foot of gas in B. T. U.								
	G. Pres.									
—27°	1	27.30	27.01	26.73	26.44	26.16	25.87	25.59	25.30	25.02
—20°	4	33.74	33.40	33.04	32.70	32.34	31.99	31.64	31.30	30.94
—15°	6	36.36	36.48	36.10	35.72	35.34	34.96	34.58	34.20	33.82
—10°	9	42.28	41.84	41.41	40.97	40.54	40.10	39.67	39.23	38.80
— 5°	13	48.31	47.81	47.32	46.82	46.33	45.83	45.34	44.84	44.35
0°	16	54.88	54.32	53.76	53.20	52.64	52.08	51.52	50.96	50.40
5°	20	61.50	60.87	60.25	59.62	59.00	58.37	57.75	57.12	56.50
10°	24	68.66	67.97	67.27	66.58	65.88	65.19	64.49	63.80	63.10
15°	28	75.88	75.12	74.35	73.59	72.82	72.06	71.29	70.53	69.76
20°	33	85.15	84.30	83.44	82.59	81.73	80.88	80.02	79.17	78.31
25°	39	95.50	94.54	93.59	92.63	91.68	90.72	89.97	88.81	87.86
30°	45	106.21	105.15	104.09	103.03	101.97	100.91	99.85	98.79	97.73
35°	51	115.69	114.54	123.39	112.24	111.09	109.94	108.79	107.64	106.49

The density of ammonia gas varies approximately as the absolute pressure, in consequence of which the refrigerating capacity of a given compressor varies directly with the absolute suction pressure, therefore a compressor working under a suction pressure of 30 pounds will have approximately 50 per cent. greater capacity than one working under 15 pounds gauge pressure.

To determine the net amount of refrigeration resulting from the evaporation of one pound of liquid ammonia at a given back pressure, it is necessary to make a deduction from the latent heat of evaporation at that pressure for the energy expended to cool the ammonia itself from the temperature at which it enters the evaporating coils to the temperature at which evaporation occurs.

The temperature at which the ammonia enters the evaporating coils should be but very little higher than that of the water flowing away from the ammonia condenser. In Table XV is given the number of cubic feet of ammonia gas that must be pumped per minute at different condenser and suction pressures to produce one ton of refrigeration in twenty-four hours. The values given in this table are theoretical and it is assumed that the temperatures of the ammonia entering the evaporating coils correspond to the temperatures of condensation and the pressures given.

Consequently no allowance is made for the unavoidable losses. The unavoidable losses, however, make it necessary to add about 20 per cent. to the theoretic values in order to determine the ordinary commercial rating of a compressor.

To determine the net refrigerating effect of a compressor then, it is necessary to know or determine:

1. The suction, or back, pressure.

2. The temperature at which ammonia enters the refrigerating coils.

3. The percentage of allowance to cover unavoidable losses.

In the operation of a plant the following conditions will be found to represent fairly average practice:

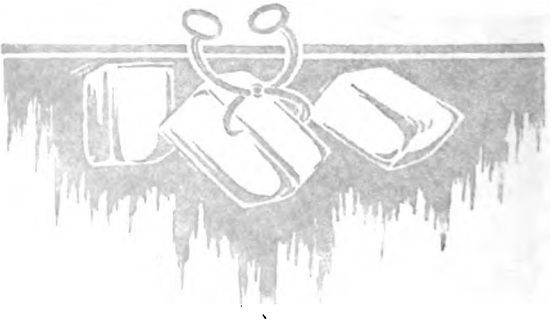
With back pressure of 15.67 pounds gauge at which pressure ammonia evaporates at 0° Fahrenheit; condensing water at 60°, which gives the ammonia liquid a temperature of about 65° Fahrenheit; under these conditions it requires the handling of about 7,500 cubic inches or 4.28 cubic feet of gas per minute to produce the effect equal to the melting of one ton of ice in twenty-four hours.

In Table XVI is shown the refrigerating effect in British thermal units of one cubic foot of ammonia gas at different condenser and suction pressures.

It will be noticed that the lower the pressure, the lower the refrigerating effect of a cubic foot of the gas. This is, because, as previously pointed out, the greater the suction pressure the denser is the gas, and the more gas in a cubic foot of space, of course, the greater the amount of specific heat it will hold or carry. It will be further observed that in order to maintain low temperatures, the suction pressure must of necessity be kept low, and this necessitates the handling of a greater amount of gas than when higher temperatures will suffice.

It would follow from this that higher temperatures and correspondingly high suction pressures, within reasonable limits are more economical to maintain than low temperatures and the corresponding low pressures.

As shown in the table, a temperature of the liquid anhydrous ammonia of 60° Fahrenheit, a temperature easily obtained by the use of cool condenser water, will give the greatest refrigerating effect under the various suction pressures.



CHAPTER VII

AMMONIA CONDENSERS

ATMOSPHERIC Condensers.—When the ammonia gas leaves a compressor cylinder, in spite of the fact that a water jacket, wet compression or oil injection was employed to keep it cool, it will flow into the discharge pipe at a temperature considerably above 100° Fahrenheit. Before the gas can be used in the refrigeration system it must be liquefied, and to liquefy the gas requires a withdrawal of heat. Heat is withdrawn from the gas in practice by means of condensers which bring the gas in contact with water-cooled pipes.

The most common type of ammonia condenser is the atmospheric condenser shown in Fig. 9. In this type of condenser the gas enters the coil at the top, flows along the upper loops of the coil until cooled enough to condense, when in its liquid form it passes to the lowest loop of the coil and out through the liquid pipe to the liquid tank or receiver. During the time the condenser is in use, a thin film of water is flowing over the outside surface of the pipes to keep them cool and carry off the excess heat of the ammonia.

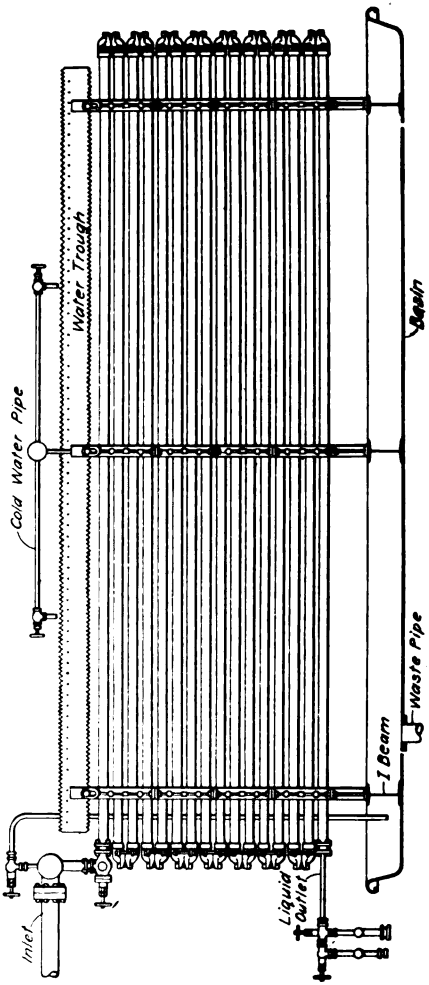


Fig. 9
Atmospheric Condenser

The cooling water from the condenser coils is collected in a basin underneath, and flows through the waste-pipe to the sewer or other point of discharge, or is

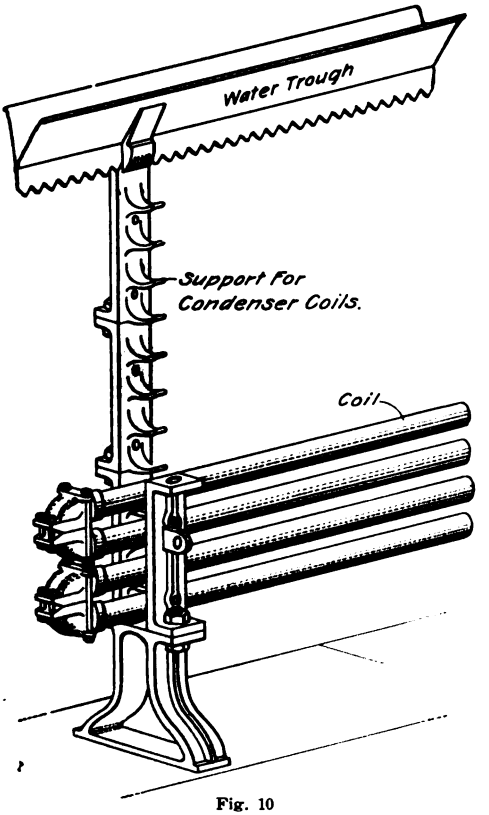


Fig. 10
Detail of Atmospheric Condenser

conducted to a receiving well or cistern from which it can be used over and over again, pumping it through the supply pipes to the condenser as soon as it has cooled.

Water Spreader for Condensers.—One of the most difficult things about the operation of an atmospheric condenser is to get a uniform and satisfactory distribution of water over all parts of the coils. Various devices have been tried for this purpose, some of which are more satisfactory than others. Perforated iron pipes are all right when first put in, but there is a tendency for some of the perforations to clog, thereby shutting off the water from portions of the condenser. Slotted pipe is more satisfactory than perforated pipe for the reasons that it is less liable to clog, and it allows the water to overflow along the entire length of the supply line. In Fig. 10 is shown one means of providing an even distribution of water to the condenser coils. A trough is formed into which the condensing water is allowed to flow. The top edges of this trough are perfectly level so that water will overflow the edges uniformly along its entire length, and a saw-tooth edge provides a better "drip" than would an ordinary straight edge. The illustration shows the water trough in its proper relation to the coils, the support on which the coils rest; and at the bottom of the support are a couple of loops of the condenser coils. An air or blow-off valve is placed at the highest point of each stand of a condenser through which to empty air from the coils.

Batteries of Atmospheric Condensers.—A single condenser coil would have capacity enough only for the smallest of refrigeration or ice-making plants, consequently, when a large plant is installed, the condensers must be arranged in batteries. A battery of atmospheric ammonia condensers is shown in Fig. 11,

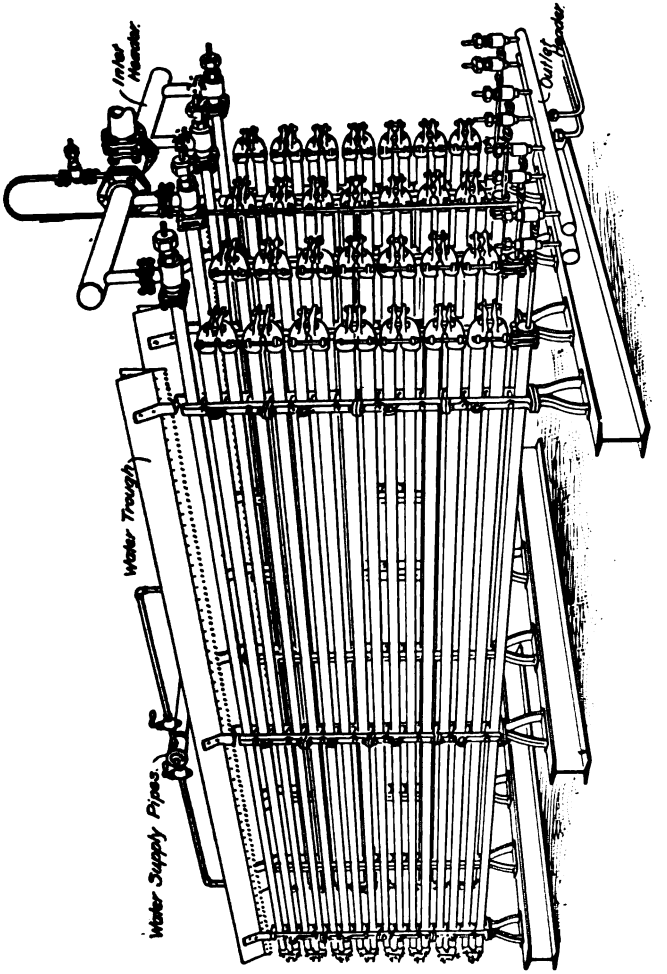


Fig. 11
Battery of Atmospheric Condensers

and consists simply of several stands of condensers grouped together and connected with inlet and outlet headers. Each stand of the condenser coil is independently valved between the inlet header and the outlet header so that it can be cut out of service for examination and repairs, or to cut down the capacity, without interfering with the other stands or coils of the battery. The loops are given a slight fall of about 1 inch in 10 feet to allow all the condensed ammonia to flow freely to the outlet header.

The size, dimensions weights, capacities and like data regarding atmospheric condensers can be found in Table XVII.

TABLE XVII

SIZE AND CAPACITY OF ATMOSPHERIC CONDENSERS

No. of Section	Capacity in Tons Refrig.	Space Required			Size, Pipe, inches	Length Pipe, feet	No. of Pipes	Total No. of feet Pipe	Shipping Weight, pounds
		Length feet	Width, feet	Height, feet					
1	7½	19½	2	8	1¼	18	20	360	2,300
2	15	19½	3	8	1¼	18	40	720	4,600
1	12½	21½	2	11¾	2	20	24	480	3,200
2	25	21½	3½	11¾	2	20	48	960	6,400
3	37½	21½	5½	11¾	2	20	72	1,440	9,600
4	50	21½	7¼	11¾	2	20	96	1,920	12,800
6	75	21½	12	11¾	2	20	144	2,880	19,200
8	100	21½	16	11¾	2	20	192	3,840	25,600
12	150	21½	24	11¾	2	20	288	5,760	38,400
16	200	21½	32	11¾	2	20	384	7,680	51,200

Counter-Current Atmospheric Ammonia Condenser.—In the ordinary atmospheric ammonia condenser, in which the hot ammonia gas enters the top loop or pipe of the coil, the hottest gas and the coolest water come in contact with the same part of the coil. The result is, when passing through the

lower loops of the coil, the liquid ammonia is in contact with pipe over which the heated cooling water is flowing, consequently it leaves the condenser at a higher temperature than though the direction of flow were reversed.

In the counter-current atmospheric condenser shown in Fig. 12 the hot gas is introduced at the bottom, instead of the top, so that it comes in contact with the hottest pipes in the coil, and as it flows upward comes successively in contact with cooler pipes until, when it reaches the top pipe in the condenser, the already chilled liquid or gas is in contact with the coldest part of the coils. Naturally, by this arrangement, the ammonia is cooled to a lower temperature.

Drip pipes are provided at every other return bend, to allow the liquid ammonia to flow away at its condensing temperature. The drips thus keep the coils free of liquid without forcing the condensed ammonia to flow back against the current of the gas.

Size of Atmospheric Condensers.—Ammonia condensers are generally made of 2-inch pipes, although 1¼-inch and 1½-inch pipes are likewise used. It has been found in practice that the temperature of the cooling water flowing over the coils rises until about the eighteenth pipe is reached, when the water has absorbed about all the heat it economically can. It is evident, therefore, that for condensing purposes it is useless to build a condenser much over 18 pipes deep. Ordinarily atmospheric condensers are usually made 20 feet in length and with 18 pipes in the coils. When abnormally warm condenser water must be used, however, coils of 24 pipes are commonly used.

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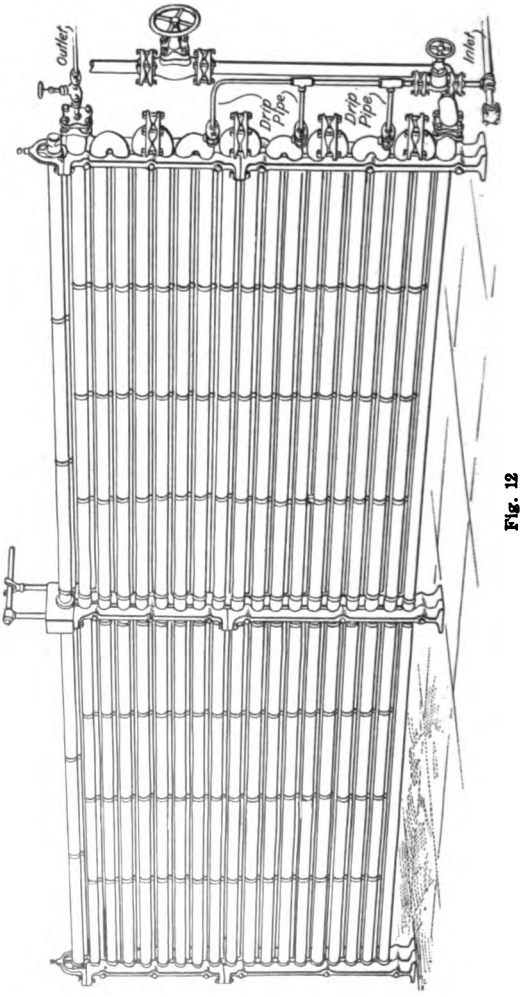


Fig. 12
Counter-current Atmospheric Ammonia Condenser

Capacity of Atmospheric Ammonia Condensers.—It is a rule established in refrigeration practice to allow 24 square feet of condensing surface per ton of refrigerating capacity, when operating with a cooling water temperature of from 58° to 70° Fahrenheit. Twenty-four square feet is equivalent to approximately 38 lineal feet of 2-inch pipe, 48 lineal feet of 1½-inch pipe or 55 lineal feet of 1¼-inch pipe; and this amount of surface must be supplied for each ton of refrigerating capacity.

Water Required for Atmospheric Condensers.—The amount of water used for condensing the ammonia in the condenser coils depends upon the temperature of the cooling water and the exposure of the condenser. Ordinarily, surface condensers require from 2½ to 3 gallons of water per minute per ton of refrigerating effort in very hot weather, when the water is likewise warm, whereas, with cool water from 50° to 60° temperature, 2 to 2½ gallons per minute would probably be sufficient.

Surface condensers are the kind most commonly used when they can be placed on a roof or in an open room where there is a free circulation of air. Owing to their economy of water, and the cooling effect of evaporation of the thin film of water flowing over the coils, they are considered very satisfactory and fairly economical.

Double-Pipe Ammonia Condensers.—In the cooling of ammonia by means of atmospheric condensers, the condenser must of right be placed on the roof or located in an open room of a building where

Fig. 13
Double-pipe Ammonia Condenser

the air can circulate freely, for evaporation of the water used in cooling has much to do with the efficiency of the condenser. It is not always possible or convenient to so locate a condenser, however, and, besides, it is often desirable to locate the condenser in a room where water flowing over the outside of the pipes would be objectionable. Under such conditions, a double-pipe ammonia cooler similar to the one shown in Fig. 13 may be used. This is a double-pipe coil made up of one pipe inside of another, with a space between the two pipes for the ammonia to circulate. The outer pipes are 2 inches in diameter, and the inside pipes $1\frac{1}{4}$ inches in diameter, thus leaving an annular space of about one-sixth inch between the two pipes.

The ammonia gas is admitted to the outer pipe at the top and the water supply to the inner pipe at the bottom of the condenser coil. This gives a downward flow to the ammonia, and an upward flow to the water, bringing the warmest gas in contact with the pipe containing the warmest water, and the coldest gas or liquid in contact with the pipe containing the coldest water. The liquid gas consequently flows from the condenser at the bottom at about the same temperature as that of the water supplied.

Submerged Ammonia Condensers.—A submerged ammonia condenser, as may be seen in Fig. 14, consists of a water tank, open or closed, in which is submerged an ammonia coil. The incoming ammonia gas enters the coil at the top, where it is in contact with the hottest part of the submerged coils, passes downward through the spirals to the outlet in the

bottom of the tank. The cold-water supply is fed into the bottom of the tank, so that it will be evenly distributed around the coils, and bring the lowest spiral, which contains the coldest ammonia, in contact with the coldest water in the tank. The warm water is taken from the top, where it overflows into a pipe to

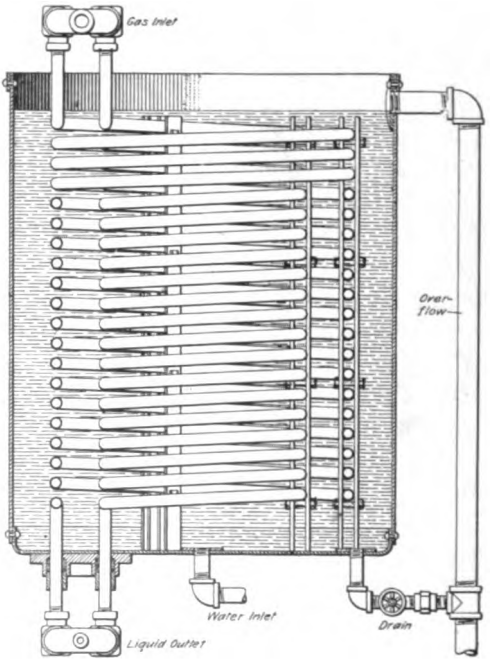


Fig. 14
Submerged Ammonia Condenser

waste, or to be conducted to a cooling cistern or tank to be used over and over again A double coil is shown in the illustration, although the number of coils will depend on the size of pipe and amount of surface required. One inch, 1¼- and 1½-inch pipes are

used for the coils, and 30 square feet of surface is allowed for each ton capacity of the machine. The coils seldom exceed 350 feet in length.

Submerged condenser tanks are deep rather than wide, so the circulating water which enters at the bottom and overflows at the top will have an opportunity of reaching a high temperature and carrying off the maximum amount of heat when leaving the tank.

The water consumption of a submerged condenser will depend upon the temperature of the water. With condensing water at 60° Fahrenheit, 2½ to 3 gallons of water per minute per ton of refrigeration is considered a fair allowance. The water inlet to a submerged condenser is generally through a perforated pipe or spreader to insure the cold water being brought into contact with the ammonia coils.

Submerged condensers are not commonly used on account of the cost. For special cases, however, they are found very satisfactory.

Functions of Ammonia Condensers.—A plentiful supply of cold water is more than desirable, it is necessary, for the ammonia condensers, for on the temperature to which the ammonia is cooled depends the efficiency of the plant. This statement can be better understood by considering just what takes place in the condenser.

From the liquid tank the liquid ammonia passes through an expansion cork to the refrigerating coils. Here the ammonia becomes heated, and must be recooled before it is available for further work. The process of compressing heats the gas still more, so that

when it reaches the condenser it contains all of the heat stored up in its cycle. This heat must be got rid of and it is by the condensing water that the heat is finally carried off from the sytem, so that, just as the fire box is what supplies heat to a heating system, conversely the condenser is the "boiler" that carries off heat from a refrigerating system, and the amount of cooling effort is proportioned to the amount of heat carried off by the water.

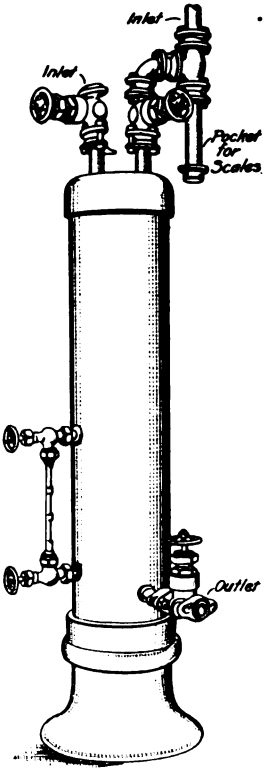


Fig. 15
Liquid Ammonia Receiver

Liquid Ammonia Receiver.—From the condenser coils the liquid ammonia flows to a liquid-ammonia receiver to be stored until called upon for use. A liquid-ammonia receiver is shown in Fig. 15, and consists simply of a wrought-iron or steel cylinder with screwed and soldered or welded heads. The smaller sizes are made vertical, and the larger sizes are usually made horizontal and are reinforced with wrought-iron bands shrunk on. The receivers are hollow inside, and stand only part full of liquid ammonia, the sight glass at the side near the bottom showing the height of liquid in the receiver. The liquid enters the receiver at the top usually by offsetting the line and

providing a scale pocket at the foot of the line to trap out any iron scales carried along with the liquid. From the outlet at the bottom of the receiver the liquid flows to the expansion valve.

Stock sizes and capacities of liquid ammonia receivers may be found in Table XVIII.

Liquid ammonia receivers generally have a storage capacity of one-half gallon for every ton capacity of the plant.

TABLE XVIII

SIZES AND CAPACITIES OF AMMONIA RECEIVERS

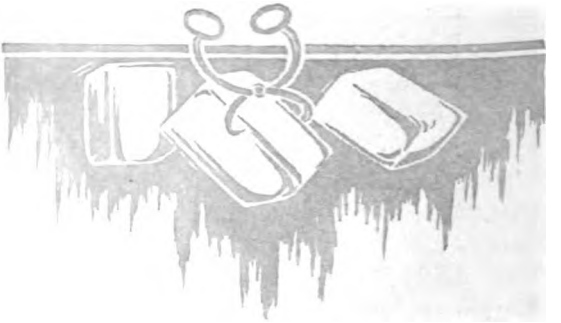
Length in feet	4	6	8	4	6	8	10	8	10
Diameter in inches	10	10	10	12	12	12	12	15	15
Approximate capacity in gallons	16	25	33	23	33	47	60	97	121
Length in feet	12	10	12	14	12	14	12	14	16
Diameter in inches	15	18	18	18	20	20	22	22	22
Approximate capacity in gallons	146	132	158	185	194	226	232	272	310

The ammonia in a receiver has been liquefied by cold and pressure, and in order to keep it in the liquid state both pressure and the corresponding temperature must be maintained. In practice, therefore, the liquid ammonia tank is covered with some good non heat conducting material to prevent the absorption of heat from surrounding objects. This is necessary as ordinarily the receiver is located in the engine room which is heated to a comfortable degree by the movement of the machinery and the steam supplying the engine and pump.

It is well a practice to so connect the feed line to the liquid ammonia tank that scales or the frozen objects cannot fall into the tank or be carried there

by the liquid ammonia from the condenser. The expansion valves from the liquid ammonia tank to the various coils are small, some of them needle valves with very small passage ways, and if scales should lodge in them it would be liable to obstruct them completely.

So the amount of liquid ammonia on hand at all times can be told at a glance, a gauge glass is attached to the receiver near the bottom, thus permitting the engineer in charge to see when the liquid ammonia is getting low.



EXPANSION VALVES AND COILS

EXPANSION Valve.—In Fig. 16 is shown a sectional view of an expansion valve. The particular features of this fitting which distinguish it from other types of angle valves are its great strength, extra deep packing box around the valve stem, cone-shaped seat and valve and small inlet for the liquid ammonia. While this illustration shows an angle valve, a globe pattern can be used, or ground key cocks may be used instead of valves. The choice of fitting used depends to a great extent upon the designer of the refrigerating plant. As was before pointed out, brass valves cannot be used in an ammonia system of refrigeration, as the ammonia would soon destroy the alloy. Iron valves are generally used instead.

Expansion Coils.—The expansion coils are to a refrigeration system what the radiators are to a steam system of heating. It is through the expansion coils that heat is abstracted from an enclosure, and, conversely, through the medium of radiators that heat is supplied to an enclosure. The functions are the same, but the operations opposite.

Direct-expansion ammonia coils are shown located in a cold-storage room in Fig. 17. The illustration shows the coils extending around only three sides of the room, whereas they may and no doubt would be carried around all four sides. In some cases they would likewise be placed under the ceiling, and in special cases multiple coils of six rows or more would be suspended from the ceiling. The coil shown in this etching is a continuous one. As a matter of fact, in large storage spaces several separate coils would be used, each provided with its own expansion valve and discharge valve so that any one or all of them could be cut out of service when occasion required. As the coldest air in a room will always be found near the floor line and the hottest near the ceiling it is advisable to place the top round of the top coil within a few inches of the ceiling, space being allowed only for the accumulation of ice on the pipes.

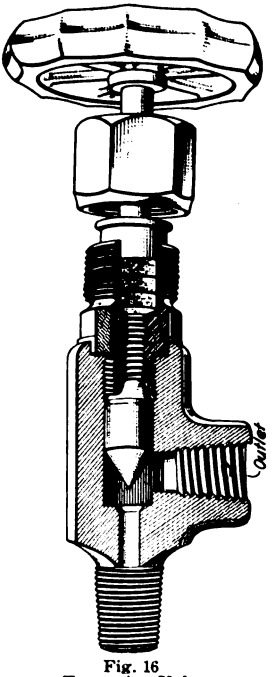


Fig. 16
Expansion Valve

Drip troughs are generally run under the lowest pipe in the expansion coil to catch the melted frost when ammonia is shut off from the coils.

These drip troughs discharge into a barrel, but for sanitary reasons, as well as to avoid freezing of

drain pipes where they pass through freezing rooms, are not discharged into the drainage system.

Supports for Direct Expansion Coils.—Cooling coils, whether the direct expansion ammonia coils or brine circulation pipes, should be kept free from the walls 3 inches or more to allow space for the air to circulate around them, even when the pipes are bedded in ice, as they generally are. The manner in which cooling coils are attached to side walls is shown

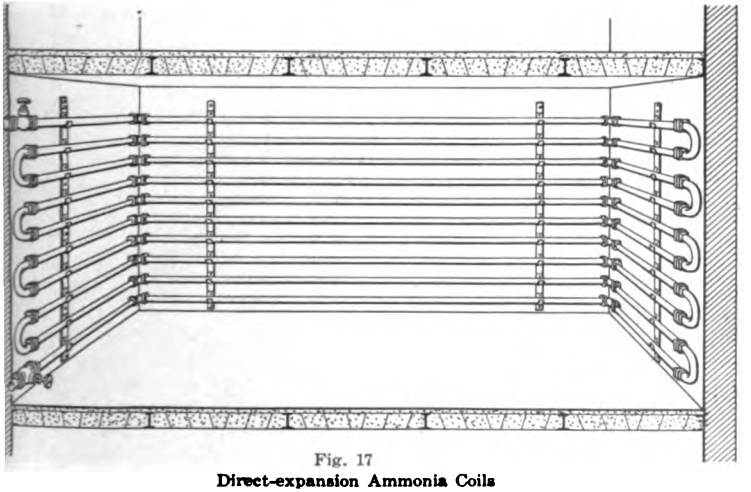


Fig. 17
Direct-expansion Ammonia Coils

in Fig. 18. Pipe rests, spaced the right distance apart, are simply attached to an offset bracket, which holds the rests the right distance from the walls. The illustration likewise shows how the pipes become bedded in ice, the ice sometimes accumulating to such an extent that it runs together, binding all the pipes of a coil into one mass. Occasionally the ice bedding

the pipes has to be removed in whole or in parts, and a new start made.

In Fig. 19 is shown a single coil hanger for supporting a coil from an I beam in the ceiling overhead. The supports on this hanger can be turned to support pipes running parallel with the beams or may be

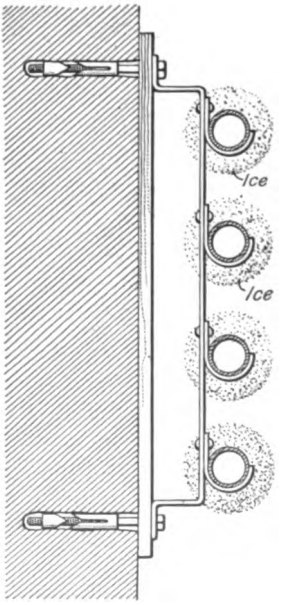


Fig. 18
Wall Support for Expansion Coil

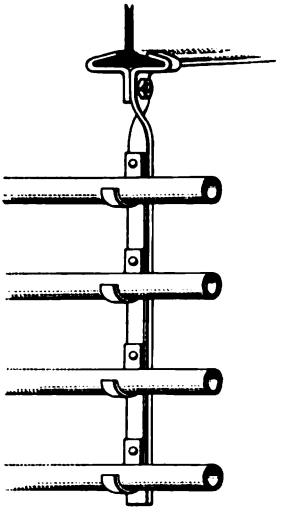


Fig. 19
Hanging Support for Cooling Coil

had for pipes running at any angle to the beams. Where several coils are to be supported from the ceiling, they may be arranged as shown in Fig. 20. This is a simple but satisfactory method, and one commonly resorted to.

Size of Direct-Expansion Coils.—The pipes used in direct-expansion ammonia coils range in size from 1 inch to 2 inches in diameter, with an average of 1½ inch in diameter.

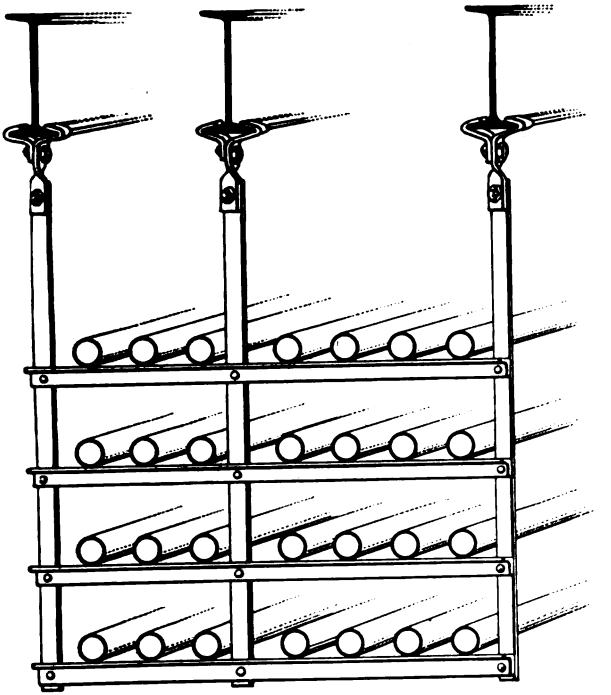


Fig. 20
Hangers for Ceiling Coils

The coils are made with large sweeping return bends, and the pipes are preferably joined together with pipe welds. In the direct-expansion system of refrigeration, 5,000 feet of 1½ inch pipe can be used in one coil and fed with a ½-inch liquid ammonia feed line. There are known cases where as many as 8,000

feet of 1½ inch pipe have been worked in one coil, but it is not safe to go beyond 5,000 feet, for in doing so it would probably require so much liquid in the start that it could not be expanded properly, and the feed end of the coil would begin to thaw. This is likely to happen in any size coil when too large a volume of liquid is allowed to enter at once.

While 5,000 feet of 1½ inch pipe can be supplied at one time, in practice it is customary to divide up the total amount of direct-expansion piping into coils of from 300 lineal feet to 1,500 lineal feet, according to the size of the rooms. The dividing up of the expansion pipes into small coils not only ensures the highest efficiency of the coils, but it furthermore makes possible the regulation of temperature within the storage enclosure, so that any temperature from 0° to 55° Fahrenheit, which covers the whole range of ordinary refrigeration, can be maintained, provided there is sufficient pipe surface in the coils. The temperatures desired in the storage of various foodstuffs can be found in Table XIX.

Capacity of Direct-Expansion Coils.—The work to be performed by expansion coils in carrying off heat from an enclosure vary so that no certain amount of piping or radiation can be determined as for steam heating, and that amount of surface be depended upon to take care of all conditions. For instance, an enclosure might be almost empty one hour, and the next have stored within it tons and tons of goods at ordinary temperature, which must be chilled to the temperature of the room, and maintained at that temperature. This would necessitate the

TABLE XIX

COLD STORAGE TEMPERATURES

Articles	Degrees Fahr.
FRUIT	
Apples	32–36
Bananas	34
Berries, fresh	36
Cranberries	33–36
Cantaloupes	40
Dates, Figs, etc.	50–55
Fruits, dried	35–40
Grapes	34–36
Lemons	33–36
Oranges	34–36
Peaches	34–36
Pears, Watermelons	34–36
MEATS	
Brined	38
Beef, fresh	33
Beef, dried	36–40
Calves	32–33
Hams, Ribs, Shoulders (not brined)	20
Hogs	29–32
Lard	38
Livers	20–30
Sheep, Lambs	32
Ox-tails	30
Sausage casings	20
Tenderloin, Butts, etc.	33

Articles	Degrees Fahr.
FISH	
Fresh Fish	20
Dried Fish	36
Oysters in shell	30–35
Oysters in tubs	25
CANNED GOODS	
Sardines	35–40
Fruits	35–40
Meats	35–40
BUTTER, EGGS, ETC.	
Butter	18–20
Butterine	18–20
Cheese	34
Eggs	31
LIQUIDS	
Beer, Ale, Porter, etc.	33
Cider	30
Ginger Ale	36
Wines	40–45
FLOUR AND MEAL	
Buckwheat Flour	36–40
Corn Meal	36–40
Oat Meal	36–40
Wheat Flour	36–40

Articles	Degrees Fahr.
VEGETABLES	
Asparagus	34–35
Cabbage	34–35
Carrots	34–35
Celery	34–35
Dried Beans	32–40
Dried Corn	35
Dried Peas	35–40
Onions	36
Parsnips	34–35
Potatoes	36–40
Sauerkraut	35
MISCELLANEOUS	
Cigars, Tobacco	35
Furs, Woolens, etc.	35
Honey	45
Hops	40
Maple Syrup, Sugar	40–45
Oils	35
Poultry, dressed, iced	28–30
Poultry, dry picked	26–28
Poultry, scalded	20
Game—to freeze	15–18
Game—after frozen	25–28
Poultry—to freeze	15–18
Poultry—after frozen	25–28
Nuts in shell	35–40
Chestnuts	33

bringing into service of all the coil surface in the room until the stored products were chilled, with a corresponding increase in the work of the compressor and condenser. After the goods were chilled, the amount of coil surface in use could be gradually cut down until only enough remained to keep the storage compartment at the right temperature. It is for this reason, as pointed out before, the total pipe surface is divided up into coils.

In determining the size of direct expansion coils required empirical rules are largely followed, the capacity in feet of coil being proportioned to the cubical contents of the room and the purpose for which the room is intended, which, in turn, determines the temperature of the room. The following proportions are the ones commonly followed in practice: for high temperature work, such as breweries, packing houses and like places where the temperature to be maintained is above 32° Fahrenheit, 1 lineal foot of 1¼ inch pipe is allowed for every 16 cubic feet of space within the enclosure. For freezing rooms to be kept at a temperature of 15° Fahrenheit, 1 lineal foot of 1¼ inch pipe is allowed for each 6 cubic feet of space, and for a temperature of 7° Fahrenheit, 1 lineal foot of 1¼ inch pipe is allowed for each 3 cubic feet of space in the inclosure.

These allowances are based on a back pressure or suction pressure, of 15 pounds per square inch, which is equal to a temperature of 0° Fahrenheit. If the back pressure to be carried were 30 pounds, double the amount of expansion coil would be required, while if the back pressure were 0 or 1 pound only half of the amounts stated would be required.

Size of Feed and Return Mains.—In Table XX can be found the sizes of main feed and return pipes for refrigeration plants of various tonnages.

TABLE XX

SIZE OF DIRECT EXPANSION FEED AND RETURN MAINS

Refrigerating Capacity	Size of Main Feed Line for Liquid Ammonia	Size of Suction Pipe or Main Return
5 tons	½ inch	1¼ inch
10 "	½ "	1½ "
25 "	½ "	2 "
40 "	¾ "	2½ "
75 "	1 "	3 "
120 "	1¼ "	4 "

The sizes given in the table, it must be remembered, are for refrigerating—not ice making—tonnage, and are the smallest sizes that can be used for the purpose. They are based on a gas velocity of 80 feet per second, and a length of travel of 100 feet. If the distance be increased to over 100 feet, or the velocity of the gas be less than 80 feet per second, the pipes given in the tables should be increased to the next larger size.

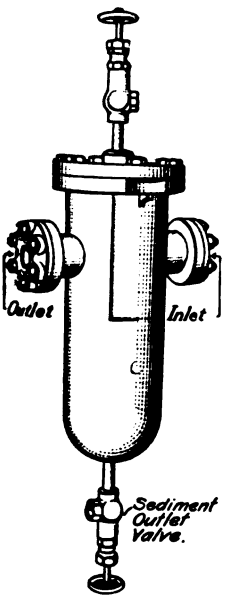
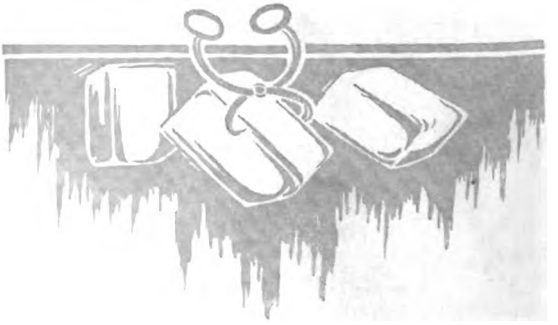


Fig. 21
Oil and Scale Trap

Oil and Scale Separators.—In Fig. 21 is shown an oil and scale separator. These are used on the suction line from the direct expansion coils to the compressor, for the removal of scales, oil or any other foreign matter that may be taken up

by the ammonia gas. The chamber shown in the illustration is provided with baffle plates inside, so arranged that any scales, oil, dirt or foreign matter of any kind are separated from the ammonia gas and deposited in the bottom of the separator, from where it can be blown out through the purging or sediment valve at the bottom.



REFRIGERATION PIPES AND FITTINGS

CHAPTER IX

REFRIGERATION PIPES

WROUGHT Pipe.—On account of the heavy pressures under which refrigerating plants operate and the necessity for having them perfectly tight, extra strong pipe is generally used for all the principal parts, although standard-weight pipe is used for the water supply and for other purposes for which it is suitable. In Table XXI will be found the weights and dimensions of the various sizes of standard-weight pipes.

For refrigeration purposes proper, black iron pipes are used, while for water supply and other purposes around the plant galvanized pipe may be used. The sizes and dimensions of extra-strong wrought pipes, both plain and galvanized, can be found in Table XXII.

TABLE XXI

SIZE AND DIMENSIONS OF STANDARD WROUGHT PIPE

Nominal Internal Inches	Diameter Actual External Inches	Diameter Actual Internal Inches	Thickness Inches	Circumference External Inches	Circumference Internal Inches	Transverse Areas External Square Inch	Transverse Areas Internal Square Inch	Transverse Areas Metal Square Inch	Length of Pipe per Sq. Foot of External Surface Feet	Length of Pipe per Sq. Foot of Internal Surface Feet	Length of Pipe Containing One Cubic Foot	Weight per Foot of Length Pounds	No. of Threads per Inch of Screw	Contents in Gallons per Foot of Length	Weight of Water per Foot of Length, Pounds
⅛	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27	.0006	.005
¼	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18	.0026	.021
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18	.0057	.047
½	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14	.0102	.085
¾	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14	.0230	.190
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½	.0408	.349
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½	.0638	.527
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½	.0818	.760
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½	.1632	1.356
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8	.2550	2.116
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8	.3673	3.049
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8	.4998	4.155
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8	.6528	5.405
4½	5.	4.508	.246	15.708	14.152	19.635	15.961	3.674	.764	.848	9.02	12.34	8	.8263	6.851
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8	1.020	8.500
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8	1.469	12.312
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8	1.999	16.662
8	9.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8	2.611	21.750
9	8.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8	3.300	27.500
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.005	8	4.081	34.000
11	11.25	11.25	.375	35.343	35.343	99.402	99.402	13.696	.318	.330	1.456	45.95	8	5.163	43.000
12	12.75	12.	.375	40.055	37.7	113.098	113.098	14.579	.299	.319	1.27	48.985	8	5.875	48.930

While extra-strong pipe is commonly used for ammonia refrigeration purposes, there are occasions where double-extra-strong pipe is used, and in carbonic anhydride refrigeration systems, where extremely high pressures are necessary, double-extra-strong pipes are commonly used. The sizes and dimensions of double-extra-strong pipe can be found in Table XXIII.

The outside diameters of the corresponding sizes of standard, extra-strong and double-extra-strong pipes are the same, consequently the bore of the heavier-weight pipes must be smaller than the bore of standard-weight pipes of like sizes. The difference is not of so much importance in large-size pipes, but for the smaller sizes increasing the weight cuts down the capacity more than would be expected. For instance, the cross sectional area of a ½-inch standard-weight pipe is .3048 square inch; of a ½-inch extra-strong wrought pipe .231 square inch, and of a ½-inch double-extra-strong wrought pipe only .047 square inch, or only about one-fifth the area of the extra-strong pipe.

Wrought pipe can be had for refrigeration purposes galvanized both inside and outside, or galvanized only on the inside or outside as desired.

Joints for Refrigeration Piping.—It is of the utmost importance to have all the piping around a refrigeration plant perfectly tight, for ammonia has an injurious effect upon many stored products; mixed with air in certain proportions it is explosive, and it is injurious to health if inhaled, while prolonged inhalation of a strong mixture will cause death. On account of the importance of maintaining a perfectly

TABLE XXII

SIZE AND DIMENSIONS OF EXTRA-STRONG PIPE

Diameter			Thickness	Nearest Wire Gauge	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Nominal Weight
Nominal Internal Inches	Actual External Inches	Actual Internal Inches	Inches	Number	External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet	per Foot, Pounds
⅛	.405	.205	.1	12½	1.272	.644	.129	.033	.086	9.433	18.632	.29
¼	.54	.294	.123	11	1.696	.924	.229	.068	.161	7.075	12.986	.54
⅜	.675	.421	.127	10½	2 121	1.323	.358	.139	.219	5.657	9.07	.74
½	.84	.542	.149	9	2.639	1.703	.554	.231	.323	4.547	7.046	1.09
¾	1.05	.736	.157	8½	3.209	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	7	4.131	2.988	1.358	.71	.648	2.904	4.016	2.17
1¼	1.66	1.272	.194	6½	5.215	3.996	2.164	1.271	.893	2.301	3.003	3.
1½	1.9	1.494	.203	6	5.969	4.694	2.835	1.753	1.082	2.01	2.556	3.63
2	2.375	1.933	.221	5	7.461	6.073	4.43	2.935	1.495	1.608	1.975	5.02
2½	2.875	2.315	.28	2	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.5	2.892	.304	1	10.996	9.085	9.621	6.569	3.052	1.091	1.328	10.25
3½	4.	3.358	.321	0	12.566	10.549	12.566	8.856	3.71	.955	1.137	12.47
4	4.5	3.818	.341	0	14.137	11.995	15.904	11.449	4.455	.849	1.	14.97
5	5.563	4.813	.375	00	17.477	15.120	24.306	18.193	6.12	.687	.793	20.51
6	6.625	5.75	.437	000	20.813	18.064	34.472	25 967	8.505	.577	.664	28.58

TABLE XXIII

SIZE AND DIMENSIONS OF DOUBLE-EXTRA-STRONG PIPES

Diameter			Thickness Inches	Nearest Wire Gauge Number	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Nominal Weight per Foot, Pounds
Nominal Internal Inches	Actual External Inches	Actual Internal Inches			External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet	
½	.84	.214	.298	1	2.639	.766	.554	.047	.507	4.547	15.667	1.7
¾	1.05	.422	.314	1	3.299	1.326	.866	.139	.727	3.637	9.049	2.44
1	1.315	.587	.364	00	4.131	1.844	1.358	.271	1.087	2.904	6.508	3.65
1¼	1.66	.885	.388	00	5.215	2.78	2.164	.615	1.549	2.304	4.317	5.2
1½	1.9	1.088	.406	000	5.969	3.418	2.835	.93	1.905	2.01	3.511	6.4
2	2.375	1.491	.442	0000	7.461	4.684	4.43	1.744	2.686	1.608	2.561	9.02
2½	2.875	1.755	.560	M—	9.032	5.513	6.492	2.419	4.073	1.328	2.176	13.68
3	3.5	2.284	.608	⅝—	10.996	7.175	9.621	4.097	5.524	1.091	1.672	18.56
3½	4.	2.716	.642	⅝+	12.566	8.533	12.566	5.794	6.772	.955	1.406	22.75
4	4.5	3.136	.682	M—	14.137	9.852	15.904	7.724	8.18	.849	1.217	27.48
5	5.563	4.063	.75	¾	17.477	12.764	24.306	12.965	11.34	.687	.940	38.12
6	6.625	4.875	.875	⅞	20.813	15.315	34.472	18.666	15.896	.577	.784	53.11

tight piping system, the ordinary screw joints and common water and steam fittings of commerce are not used for the ammonia circulation system or the brine system in refrigeration work, but special fittings with improved joints are used for this purpose. A split ammonia bend which shows a feature common to all ammonia fittings may be seen in Fig. 22. This fitting is threaded like ordinary fittings, but differs from them in this respect, that at the point marked *a* there is a recess which forms an annular space around the pipe when the pipe and fitting are screwed together. This annular recess, or space in some form or other, is common to ammonia fittings, the manner in which it is utilized only differing in different methods. One of the most common methods is to use this recess in connection with a packing of rubber, and a gland similar to the one shown in Fig. 23. The manner of making tight a pipe joint by means of a gland is shown in Fig. 24. The ammonia fitting with which the gland is to be used has lugs cast on it, with holes for bolts to pass through. The gland and rubber packing are slipped over the pipe before it is screwed in place in the fitting, then after the threads are made up the gland is pressed down into place and the bolts tightened up, thereby expanding the rubber and forcing it into all crevices of pipe thread and fitting recess. Should the threads of pipe and fitting leak, this rubber packing and gland will keep the ammonia from escaping into the building; while

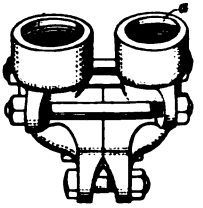


Fig. 22
Fitting with Packing Recess

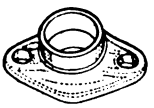


Fig. 23
Packing Gland

if at any future time a leak should develop the gland can be screwed down still tighter to stop the leak. Instead of a gland, as shown in the illustration, in some systems a lock nut or jam nut is used, together with a rubber gasket which projects above the recess when it is in place. To make the joint tight or stop a leak the jam nut is screwed down hard, thereby compressing the rubber gasket and forcing it into all the crevices of pipe thread and fitting.

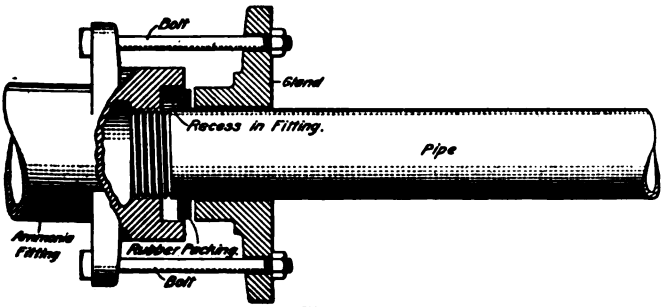


Fig. 24
Ammonia Pipe Joint

Still another method of making tight joints is to use malleable iron or steel fittings which have recesses the same as in the other two cases, but instead of using rubber gaskets and a lock nut or gland the threads are sweated together with solder, and the recesses in the fittings are filled with solder. A return bend, such as is commonly used for a condenser coil or expansion coil, is shown in Fig. 25. It will be noticed that this fitting has a gland on each of the outlets.

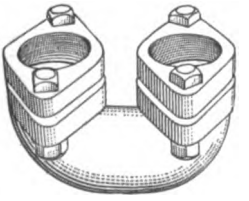


Fig. 25
Return Bend

Ammonia unions are made up with lead gaskets, the gasket being placed in a recess in the female half of the flange, while a gland on the male part of the flange presses on it when in place. An oval flange union composed of the male and female parts can be seen in Fig. 26. The male glandis at *a* and the female recess at *b*. The washer is not shown. This flange, it will be observed, is oval and is held together with only two bolts. While this is permissible for the small sizes of pipes, for large pipes four or more bolts should be used according to the size of the pipe line. The two parts of a square flange with four bolt holes are shown in Fig. 27, the male gland being marked *a* and the female recess *b*.

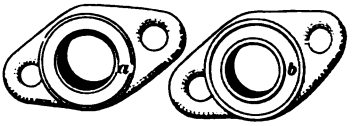


Fig. 26
Oval Flange

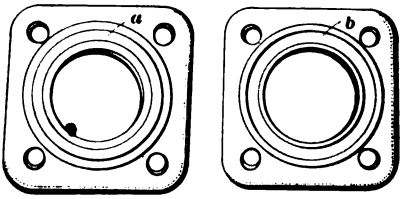


Fig. 27
Square Flange

Flange unions are an important part of a refrigeration system, being used in expansion coils instead of ordinary pipe couplings, which are never used in the high-pressure or direct-acting system of refrigeration.

When an ammonia line is exposed to extremes of temperature or when the contraction and expansion from cooling and heating amount to more than can be taken up by the bends and springs of the system, an ammonia expansion joint should be used. A fitting of this description is shown in Fig. 28. In principle of

construction these differs none from the expansion joints used in steam work, but they are made stronger in all parts, so they will remain tight under whatever movement takes place—for a leak of ammonia might prove dangerous, while a leak of steam would be only wasteful. In large installations and central-station refrigeration plants, instead of union-flange joints the pipes are sometimes welded, end to end, by means of thermit or electrically.

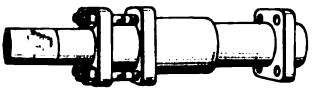


Fig. 28
Expansion Joint

Wrought iron or steel pipe may be used in refrigeration systems.

So far as length of life is concerned, or deterioration from pitting, there is practically no difference between the two materials. When it comes to strength, however, the odds are in favor of steel pipe. This is true not only of the walls of the pipe, but of the seams as well, which is an important consideration.

Steel pipe is more pliable than wrought iron pipe, and on account of this greater pliability, which permits steel pipe being bent and twisted without opening at the seam or otherwise failing, it makes a better material for refrigeration installation where numerous pipe bends are to be made. It might be well to note that in the bending of wrought pipe there is less liability of it failing at the seam if the pipe is held so the weld will be at the side, not at the top or bottom.

Heavy wrought pipe that is galvanized on the inside, but not on the outside, or galvanized on the outside without being galvanized on the inside, is of advantage in prolonging the life of the pipe. For instance atmospheric condensers can be made of pipes galvanized on the outside so they will resist the corrosive effect of air and water, while at the same time the inside of the pipe is black, which is not affected by the ammonia.

CHAPTER X

TYPES OF AMMONIA FITTINGS

RETURN Bends.—As return-bend coils form a considerable part of a refrigeration system, return bends naturally are among the fittings most commonly used, and the types of return bends are as numerous almost as there are manufacturers. A split ammonia return bend has already been shown in Fig. 22. In Fig. 29 can be seen an entirely different type, being a bend made of wrought pipe with flanged ends. A return bend of this type

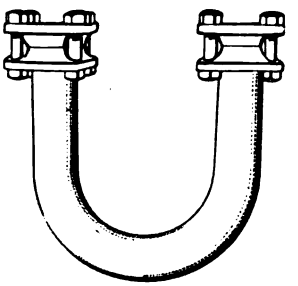


Fig. 29
Wrought Pipe Return Bend

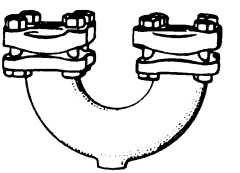


Fig. 30
Cast Iron Return Bend

with long radius curves and uniform bore throughout offers the least frictional resistance of any of the return bends, but the pipes in the coils are so far

apart that they cannot be used when space is at a premium. A cast return bend is shown in Fig. 30. This fitting has easy curves and brings the pipes of a coil, particularly an expansion coil, as close together as is desirable, for in use ice will form on the pipes of an expansion coil, completely embedding them, and forming in one mass if the pipes are too close together.

Another type of return bend with short-radius square curves or corners is shown in Fig. 31. This fitting, like the other, has flanged ends so the fitting can be removed from a coil without disturbing the pipes of the coil. This is a characteristic of most return bends used in refrigeration practice, which enables either a pipe or a fitting to be removed without tearing down part of the coil to get at the defective pipe, as would be the case if ordinary screw fittings were used.

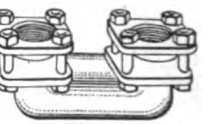


Fig. 31
Short Radius
Return Bend

Elbows, or Quarter Bends.—In the illustration Fig. 32 is shown an ordinary quarter bend, or elbow, made of cast iron, malleable iron or cast steel, and fitted with flanges. This is a short-radius bend, but the kind most commonly used in practice. The curves of this fitting are sufficiently easy to permit a free flow of gas or water without offering too great frictional resistance.

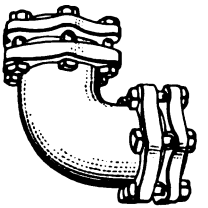


Fig. 32
Cast Quarter Bend

A semi-steel elbow of long, sweeping curves is shown in Fig. 33, with the female portion of a flange

on one end and the male portion on the other. Fittings of this description will be found very satisfactory for the main pipes around the compressor, while the other fitting may be safely used on coils and the minor piping within the system.

Tee Fittings.—One type of tee fitting used in refrigeration practice is shown in Fig. 34. Like all the fittings previously shown it has flanged or gland ends, and does not depend upon ordinary screw thread for the joint. This placing of a flange union or disconnecting device at all the principal fittings in a coil makes the work of installation comparatively costly, but keeps down the cost of repairs to the minimum. Tee fittings are made with easy curves leading to the branch, instead of the square angles shown in the illustration, and such fittings, of course, offer less frictional resistance to the gases or fumes passing through them.

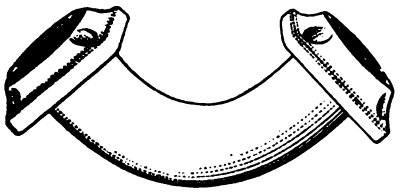


Fig. 33
Semi-Steel Elbow

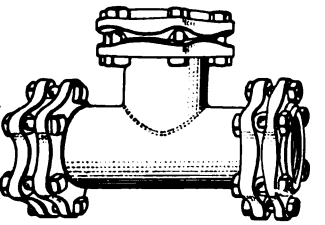


Fig. 34
Tee Fitting

Cross Fittings.—A cross fitting of square angles and with flanged ends is shown in Fig. 35, and a cross fitting with gland ends and Y or easy-curve angles is shown in Fig. 36. Both of these are of stock design.

The foregoing illustrations of fittings are given only to show certain types and point out the difference between the fittings used in refrigeration practice and those used in steam and water installations. Each type of fitting shown has many modifications, while numerous fittings, such as coil headers and special header fittings, commonly used are not shown at all.

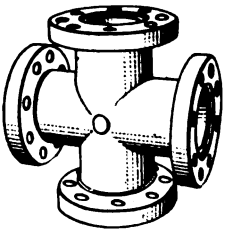


Fig. 35
Square Angle Cross Fitting

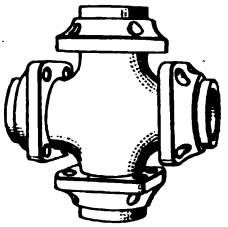


Fig. 36
Easy-Angle Cross Fitting

There is no room for them in a work of this kind, and when designing refrigeration plants the designer can find the different fittings in the various manufacturers' catalogues, which can be consulted to advantage.

Ordinary water and steam fittings are not shown, either, for the reason that they are common to pipe-fitting practice. The fact that they are not shown does not signify that they are not used in refrigeration work, for they are, and may well be outside of the ammonia system. All the water-supply, oil and other pipes can be and generally are made up with ordinary fittings.

CHAPTER XI

COCKS AND VALVES

AMMONIA Expansion Cocks.—An ammonia expansion cock is shown in perspective in Fig. 37. This expansion cock has an indicator or pointer showing when the cock is open and closed and when open just how wide open it is. In Fig. 38 is shown in perspective an ammonia expansion valve, of the straight-way pattern. Expansion valves can be had likewise in angle patterns, also three-way or tee patterns, and

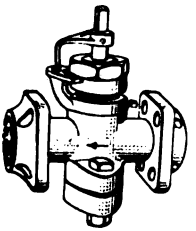


Fig. 37
Ammonia Expansion Cock

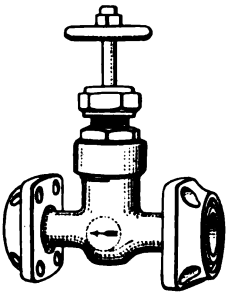


Fig. 38
Ammonia Expansion Valve

in many different designs and sizes. Ordinary stock expansion valves range in size as follows: $\frac{1}{4}$-inch, $\frac{3}{8}$-inch, $\frac{1}{2}$-inch, $\frac{3}{4}$-inch, 1-inch, $1\frac{1}{4}$-inch, $1\frac{1}{2}$-inch and

2-inches in diameter. Special sizes can, of course, be made to order, but as the expansion coils are commonly divided up into sections, expansion valves larger than 2 inches will seldom be needed.

Check Valves.—Ammonia check valves are made in sizes for from ¼-inch to 5-inch pipe, and in a variety of designs. In Fig. 39 can be seen one design of check valve for small pipes, while Fig. 40 shows a check valve for pipes from 1¼ to 5 inches in diameter. The working of these valves, it might be well to state, are the same or on the same principle as check valves for steam or water pipes, from which they differ principally

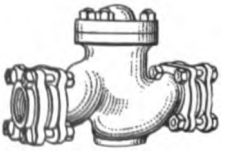


Fig. 39
Check Valve for Small Pipe

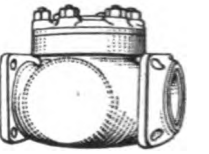


Fig. 40
Check Valve for Large Pipe

in having greater strength and no brass or copper parts in contact with the ammonia. In fact, the valves and fittings used in refrigeration practice differ in no way in principles of construction from ordinary steam and water fittings or valves. It is in the details they differ, details which give the ammonia fittings greater strength, longer life and greater ease in disconnecting.

Globe and Angle Valves.—A globe valve, such as is used in ammonia refrigeration practice, is shown in perspective in illustration Fig. 41. The heavy body, flanges, bonnet and other parts show the heavy service it will withstand. In the illustration Fig. 42 can be seen an angle valve, which differs from the

globe valve chiefly in that it forms a 90-degree bend instead of being a straightway opening. Globe valves are used on straight runs of pipe, and angle valves when two pipes come together at right angles.

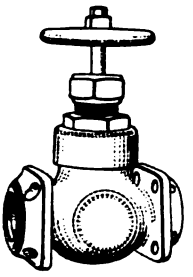


Fig. 41
Globe Valve

Fig. 42
Angle Valve

In the three-way valve, shown in Fig. 43, is combined a double-angle valve or tee valve. Gas or liquid enters the valve through the bottom opening, and is admitted to the coils or pipes on each side of the valve. The special four-way valve, shown in Fig. 44, goes a step further and from the one inlet supplies three outlets, which might be coils or ordinary branch supply pipes.

Thermometer Connections to Refrigeration System.—In order to take the temperature of the ammonia or brine in different parts of the refrigeration system it is necessary to be able to place the bulb of the thermometer in the pipe in such a way that it can register the temperature within. In practice this is done by means of thermometer cups, similar to the one shown in Fig. 45, which are screwed permanently into the piping system. The mercury

cup, which has a bore of just sufficient size to permit the introduction of the mercury cup of a thermometer, is screwed into a fitting in such a way that the thin metallic walls are in contact with the fluid within.

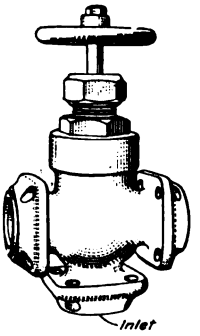


Fig. 43
Three-way Valve

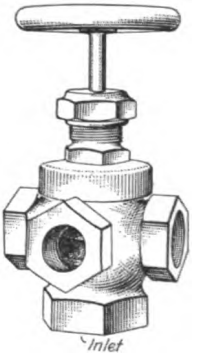


Fig. 44
Four-way Valve

The cup is partly filled with mercury, which acts as a conductor of heat from the mercury bulb of the thermometer to the walls of the cup, which being in contact with the refrigerating medium in the pipe is of the same temperature. For refrigeration work this mercury cup must be of iron or some alloy which will not be affected by ammonia or mercury—copper or brass are not suitable for this purpose. A plug is very desirable to screw into this mercury cup when the thermometer is removed, to prevent the loss of mercury or filling of the cup with dirt or other foreign matter.

Thermometers are more used in brine circulation systems than in the ammonia portion of a refrigeration plant, for the reason that there is an intimate relation between pressure and temperature of confined

ammonia gas which can be indicated by pressure gauges which are commonly used.

Thermometer cups are generally left in place as permanent fixtures and the thermometers may be

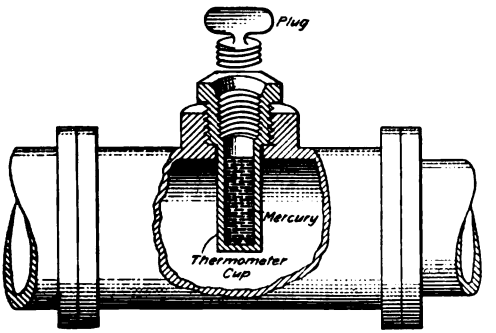


Fig. 45
Thermometer Cup

left permanently in place or put in the cups to take readings. When the thermometers are screwed in to take readings they should be allowed to remain in place ten or fifteen minutes to attain their minimum temperature before the readings are taken. It is well to see that the cups are set true when screwed into a fitting, so the thermometers will have true perpendicular positions when set in place.

Fig. 46
Thermometer

A thermometer suitable for screwing into a mercury cup is shown in Fig. 46. These may be had with Fahrenheit readings, with Centigrade readings, or with both Fahrenheit and Centigrade readings. The threaded portion *a* of the thermometer screws into the threaded neck of the mercury cup, and the thermometer cup *b* projects down into and is surrounded by the mercury

in the mercury cup. The mercury in the cups and the metals of the walls of the cup being good conductors of heat, the temperature indicated by the thermometer will be practically that of the gas or liquid flowing with the pipe.

HEAT INSULATION

CHAPTER XII

INSULATING COLD-STORAGE ROOMS

THE two essential features to be considered in the erection of cold-storage buildings are the machinery and the insulation. Refrigerating apparatus is only a means of removing heat, and insulation is only a means of preventing, as far as possible, the return of the heat after it has been removed.

A high degree of perfection has been reached in the design and construction of refrigeration apparatus, but perfect insulation is an impossibility, otherwise no refrigeration would be necessary other than to freeze the goods to the desired temperature before placing them in a perfectly insulated room.

It is estimated, after a careful calculation, that in the average cold-storage building 70 per cent. of the refrigeration applied is used to remove the heat

which leaks through the insulated walls. As this waste is continuous it is of the utmost importance to use material which will reduce it to the minimum. It is a fact that good insulation, aside from other advantages, affords a constant saving, which will make a large difference with the profit and loss account of a cold-storage plant. Poor insulation is not only a cause of annoyance, but a continuous expense, owing to the loss of refrigeration resulting from its use.

When selecting insulating materials it should be borne in mind that dead-air space is among the very best of heat insulators or retardants. If the air has room for circulation, however, the insulating effect will be destroyed. That is why materials like mineral wool, which of themselves are heat conductors, will, when packed in an air space, prove effective for insulating walls or ceilings. The mineral wool when packed into the space forms a multitude of cells which contain air, but owing to the cellular formation of the mass, the air is dead and cannot circulate.

Hollow tiles likewise prove good insulators. In the case of hollow tiles, unlike spaces filled with mineral wool, there is local circulation, but if the cells in the hollow tile are small and shallow and their ends blocked at short intervals, so air cannot ascend through them the entire height of the wall, the circulation will be of such a sluggish and restricted nature that the air is practically dead.

Besides mineral wool any fibrous or granular material which will not pack too tight will prove satisfactory for filling purposes. Among the materials successfully used may be mentioned coal cinders, hair felt, granulated cork, charcoal and sawdust.

Materials like granulated cork and charcoal rank highest for the purpose, for the reason that in themselves they are not good conductors of heat, while materials like mineral wool and cinders are, to a limited extent. On the other hand, cinders and mineral wool are fire proof, while some of the better insulating materials are not, and in designing an establishment all these facts must be taken into consideration.

Concrete is a much better insulator of heat than is generally supposed, and as this material is becoming extensively used in building construction it will become an important factor in future refrigeration design. Cork boards of varying thickness from one inch to three inches are now made, and may be used to good advantage for insulating cold-storage rooms of concrete construction. The boards are made in sizes 12 x 36 and 18 x 36 inches, and can be plastered on without further preparation, the mortar clinging to the surface of the cork board. Boards made of pressed mineral wool are likewise suitable for the purpose.

Insulating Fireproof Walls.—Certain methods for insulating walls, floors and ceilings against the loss of heat have been adopted in practice for the reasons that they are simple, effective and applicable to all conditions. The method commonly adopted for insulating walls of stone, brick or concrete is shown in Fig. 47. The inside of the wall that is to be insulated is first given two good coats of pitch, tar, asphaltum or some like elastic and moisture-proof material to prevent dampness striking into the wall and to keep down as low as possible the loss of heat due to winds.

Inside of the coat of pitch is laid a wall of hollow tile to provide a partial dead-air space. Four inches inside of the first wall of hollow tile is laid another, 3 inches thick, these two hollow-tile courses being bonded together, and between the two courses of tile the space is filled with mineral wool. The inner surface of the 3-inch hollow tiles can then be plastered with cement mortar for a finish, or, if a better finish is desired, the surface can be covered with marble or tiles. Instead of the inner course of hollow tiles glazed bricks may be laid, and the space between the bricks and the first course of hollow tile filled in with mineral wool or some other filling material, as previously explained. Further, wherever necessary or desirable to do so, one course of hollow brick can be omitted and the wall otherwise insulated just as described.

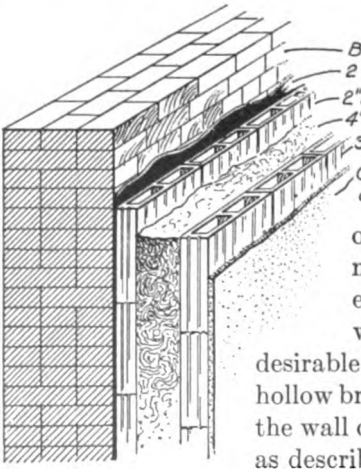


Fig. 47
Insulator for Masonry Wall

A principle of insulation which should never be lost sight of is the fact that heat being a wave motion or vibration of the ether, is transmitted most easily through a uniform medium, whereas mediums of different materials, consequently of different densities, retard and dissipate it. Therefore an insulation

should be composed of as many layers of unlike materials as is practicable, in order to retard the heat waves, which will undergo change and suffer loss with every transition made.

In the preceding example of insulation it will be seen that this principle is observed. Heat must first pass through a brick, stone or concrete wall, next through a layer of pitch or bitumen of some kind, then in succession through the wall of hollow-tile air space, recess of hollow tile, mineral wool, wall of hollow tile, air space, wall of tile and cement plaster or tile.

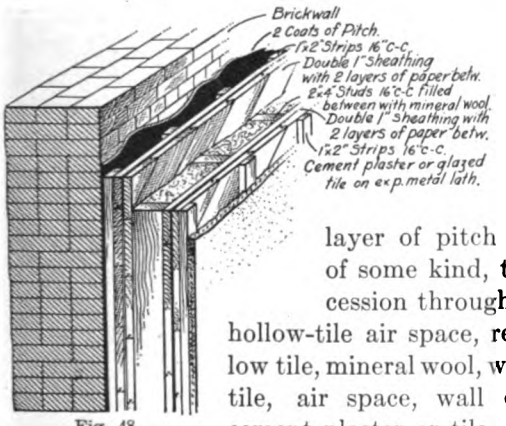

Brickwall
2 Coats of Pitch
1x2" Strips 16"c-c.
Double 1" Sheathing with 2 layers of paper betw.
2x4" Studs 16"c-c. Filled between with mineral wool
Double 1" Sheathing with 2 layers of paper betw.
1x2" Strips 16"c-c.
Cement plaster or glazed tile on exp. metal lath.

Fig. 48
Wooden Insulation for Masonry Wall

Wooden Insulation for Brickwork.—Wood is not so desirable a material as hollow tile for insulating cold-storage rooms, but, whenever for any reason wood is the chosen material, the rooms can be insulated as shown in Fig. 48. The brickwork, stone wall or cement concrete wall, as the case may be, is first treated to two coats of pitch, asphalt or tar. After the pitch has been applied regular 1 inch by 2 inch furring strips are nailed to the wall at distances of 16 inches from center to center. A horizontal course of ⅞-inch sheathing is nailed to the furring strips, a double layer of good building paper tacked to the

sheathing, and another course of sheathing, laid diagonally, is placed on top of the building paper and nailed to the furring strips through the first course of sheathing. Regular stock 2 x 4 studding are then set up on 16-inch centers and nailed to the sheathing and the face of the studding covered with a double course of sheathing with building paper between, as in the first instance. The space between the studding is then filled with mineral wool, or some other good heat insulator. Furring strips are next nailed to the surface of the last course of sheathing, and expanded metal lathing fastened to the strips, so that the surface is ready for a three-coat layer of cement plaster or for a finish of glazed tile. If the masonry walls are pretty thick, or are otherwise well insulated, the inner layer of wooden sheathing may be omitted, and the expanded metal lath nailed to the face of the 2 x 4 studding.

The sheathing used should be well matched stock, free from knot holes or shakes, and should be of some wood which will not twist and warp under the action of heat.

Insulation of Walls in Frame Buildings.—The method of insulating walls in frame buildings may be seen in Fig. 49.

This method is similar to the wooden insulation for brick walls just described, with the one exception that 2 x 4 studding takes the place of the outer 1 x 2 furring strips, and a double course of sheathing with building paper between takes the place of the brick wall and forms the outer surface of the building or wall. This method of insulation gives three air spaces

throughout the depth of the wall. In one of the 4-inch spaces the cells between the studding are filled with mineral wool so that in these the air is dead. One of the air spaces is but 1 inch deep, and as the entire width is but 14 inches and the height extends but from floor to ceiling very little circulation of air can take place within, consequently there will be but slight loss of heat due to convection. The outer air space is but 4 inches deep and greater circulation will take place in there. However, but little heat will traverse these spaces, as may be seen by placing the hand on the plaster within a frame building when the sun is beating down on the sheathing outside. Altogether, the various courses of sheathing alternating with the several air spaces will reduce the loss of heat as much as can be expected with this form of construction.

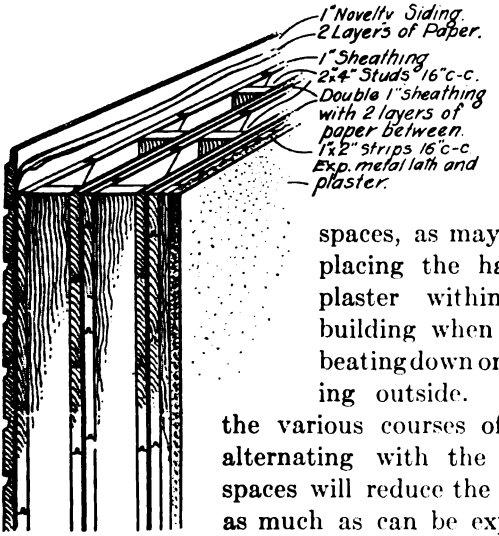

1"Novelty Siding.
2 Layers of Paper.
1" Sheathing
2x4" Studs 16"c-c.
Double 1" sheathing with 2 layers of paper between.
1"x2" strips 16"c-c.
Exp. metal lath and plaster.

Fig. 49
Insulation for Walls of Frame Buildings

An air space is of value only when the construction is perfect, when the space is no larger than three square feet and no deeper than one inch. A one-inch space will show as high heat loss as a three or four inch space.

Under these conditions air spaces increase the efficiency of any insulation approximately from 10 to 12 per cent. In other words, the amount of heat transmitted by the solid construction would be about 11 per cent. greater than after the air space was inserted, provided, however, that the air spaces are no larger than the dimensions given, and that the construction is perfect. The smaller the air space, of course, the less danger there wlll be of circulation.

The above refers to air spaces constructed by means of double tongue and groove boards with double waterproof paper between, or other materials of similar efficiency. Air spaces constructed from materials of higher efficiency increase the value of the insulation exactly in proportion to the efficiency of the material by which the air space is surrounded, for the reason that the efficiency of any air space depends exactly on the stillness of the air contained therein, and that stillness depends on the mechanical construction of the air space and on the protection afforded the air by the non-conducting qualities of the material from which the air space is constructed.

Insulation of Fireproof Ceilings.—A method of insulating a flat-arch ceiling is shown in Fig. 50. The floor tiles themselves, being double-space hollow patterns, will go a long way toward checking the conduction of heat at this point, particularly when covered on the under side with a coating of cement plaster or a surface of glazed tiles. . On top of the floor tiles is a deep bed of cinders from 6 to 10 inches in depth, and embedded in these cinders are heavy wooden sleepers to support the floor above. The

flooring consists of two heavy layers of tongue and grooved material, free from knot holes or shakes, laid up tight, with a double layer of good building paper between. The under floor is laid diagonal and the upper floor at right angles to the sleepers, so long joints in the two floors cannot coincide, and, furthermore, so the upper floor can better prevent warping of the under flooring strips. If necessary or desirable any other kind of flooring may be laid instead of a wooden one.

A cement floor, tile floor, asphalt or any other material will answer just as well and prove equally effective. There are other forms of arch besides the

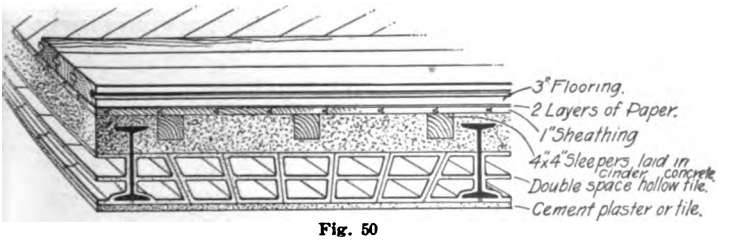


Fig. 50
Insulation of Fireproof Ceiling

flat arch and other types of ceiling tiles besides those shown in the illustration. The method of insulation, however, would apply equally to all, with whatever modifications good judgment would dictate.

Insulation of Wooden Ceilings.—In frame buildings special precautions must be taken to prevent the loss from heat which would take place through an ordinary plaster ceiling and single course of flooring above. Ceilings in frame buildings can be satisfactorily insulated as shown in Fig. 51. The

under edges of the floor joists may be covered with expanded metal and then plastered with cement mortar or covered with tiles, or, if wooden treatment is to be carried throughout the construction, the under surface of the joints can be sealed with a double course of matched ceiling boards, having a double layer of building paper between. On top of the floor or ceiling joists another double course of matched flooring is laid with two layers of good building paper between. On top of this double flooring 2-inch by 2-inch strips are nailed at intervals of 16 inches between centers; the spaces between these strips are then filled flush

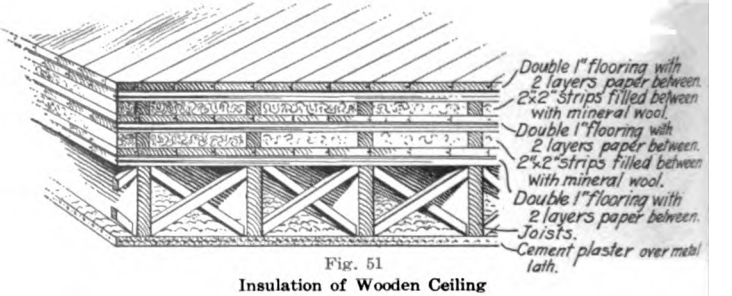

Double 1" flooring with 2 layers paper between.
2"x2" strips filled between with mineral wool.
Double 1" flooring with 2 layers paper between.
2"x2" strips filled between with mineral wool.
Double 1" flooring with 2 layers paper between.
Joists.
Cement plaster over metal lath.

Fig. 51
Insulation of Wooden Ceiling

to the top with mineral wool, and another double course of flooring is laid with building paper in between the courses. On top of this flooring 2-inch by 2-inch strips are likewise nailed, the spaces between filled with mineral wool, as in the first instance, and another double course of flooring is laid on top, with building paper placed between the courses. The top boards in this case would, of course, be the finished floor, or if cement or a tile floor is to be laid the top rows of 2-inch by 2-inch strips may be omitted and

the spaces filled with cinders, on top of which a rough bed of concrete should be laid to provide foundation for the finish course.

When laying the double floors or double courses of ceiling boards, as the case may be, one course should be run diagonally and the other at right angles to the studding, joists or furring strips.

Insulation of Ground Floor.—By the ground floor is meant the floor of the cellar or basement of a building which is in direct contact with the earth.

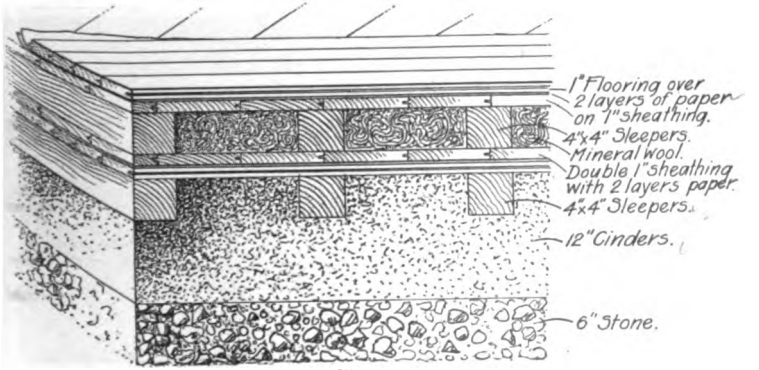


Fig. 52
Insulation of Ground Floor

There is more or less ground water stored in the soil, and from this subterranean reservoir a greater or less amount of moisture is drawn by capillarity toward the surface of the ground. Water has a great capacity for heat, and if soil moisture were allowed to rise to the ground floor of a building in which a cold-storage room was located much heat would pass into the room from the surrounding earth. To prevent such loss

due to heat, as well as to keep the ground floor dry, it may be insulated as shown in Fig. 52. The cellar bottom must first be dug out from 24 to 30 inches deeper than the line of the finish floor. The bottom of this pit is then filled to a depth of from 6 to 10 inches with rocks or crushed stones. On top of the stones is next placed a layer of good clean cinders, from 12 to 16 inches deep; embedded in these cinders, but well supported at suitable intervals, should be placed 4 x 4 inch sleepers, spaced 16 inches from center to center. On top of the sleepers there would be a

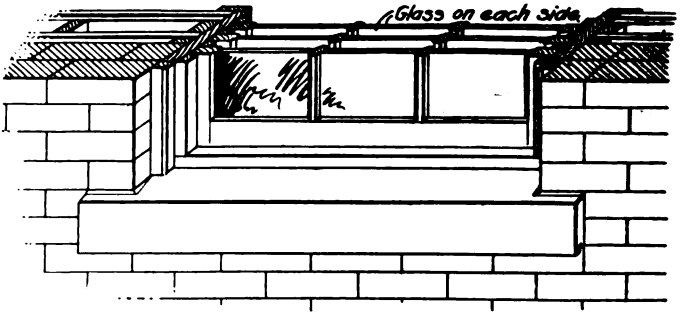


Fig. 53
Insulation of Window

regulation double floor with two layers of building paper between the courses. On top of the flooring there would be more 4 x 4 inch sleepers with the spaces between filled with mineral wool, and on top of the sleepers may be laid a regulation wooden floor consisting of two courses with building paper between, or a cement, asphalt or tile floor may be laid. It might be well to add that in case the floor is to be of tile or cement that the woodwork would be left out entirely

and the concrete and cinders depended upon for the necessary insulation.

Insulation of Windows.—When windows or skylights open into any of the cold-storage rooms of a refrigeration plant great care must be exercised to prevent the loss of power by heat conduction through the glass into the rooms. The ordinary window sash with single-thick or double-thick glass would never do for this purpose. Sash and frames of special construction must be provided. The method of insulating windows is shown in Fig. 53. Ventilation to the rooms is provided for, independent of the windows, so the sash need not be made to raise and lower like those of ordinary windows. That being true, the sash are made to fit the entire window opening and are set in place so that the leakage of air around the stops is reduced to the minimum. It will be noticed that instead of one sash three are three sash in this frame, and each sash is glazed with two panes of glass, so that all told there are six thicknesses of glass and five air spaces for the heat to pass through. In glazing windows for cold-storage rooms it is customary not to use putty and window tacks, as is commonly done in glazing, but to use adjustable stops with felt or chamois linings, so the glass will have room and freedom to expand and contract without opening crevices for the leakage of air. To avoid breakage the panes of glass should not be very large, and rolled glass should be used in preference to ordinary window glass, as rolled glass is tougher and less liable to break.

Insulation of Doors.—Wherever a passageway leads from one of the cold-storage rooms of a refrigeration plant to a warm room—that is, one maintained at the ordinary temperature of living-rooms—double doors with a lobby between will be found advisable to prevent the transmission of heat from the hot to the cooler rooms. In other parts of the establishment the opening from one room of low temperature to another of different temperature may be closed with a single door which is well insulated against the passage of heat.

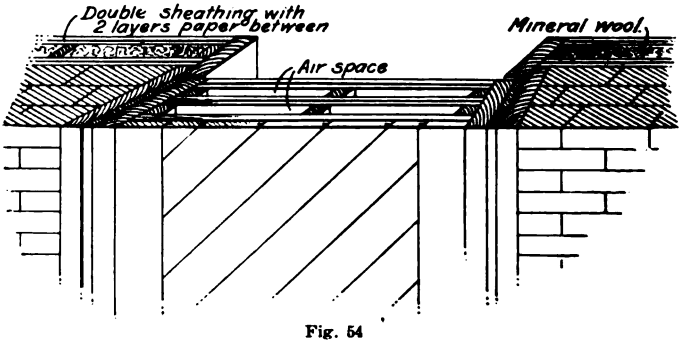


Fig. 54
Insulation of Door

An insulated door is shown in Fig. 54. This door has three double layers of boards forming a double air space, and three layers of good building paper are placed between each double thickness of board.

Relative Value of Insulating Materials.—What material will give the best insulating effect is sometimes a difficult question to determine, for not only is heat resistance to be considered but likewise the fireproof qualities of the material and their

liability to be affected by moisture are important in refrigeration design. For the purpose of insulation, rooms may be divided into dry rooms and wet rooms. Brewery refrigeration rooms and ice storage rooms are examples of wet rooms, while cold-storage and freezing rooms may be considered as dry rooms. The word dry is relative, however. In all cold-storage rooms there are times when moisture can be seen trickling down the sides or on the floor, so in insulating all cold-storage rooms it is advisable to moisture-proof them as well, to prevent moisture reaching the insulating materials or structural parts, if of wood, and

TABLE XXIV

COMPARATIVE VALUE OF DIFFERENT INSULATING MATERIALS

	Units Lost		Units Lost
Copper	515.	Brick dust	1.33
Iron	233.	Coke dust	1.29
Zinc	225.	Cork	1.15
Marble	28.	Chalk powder	0.87
Stone	17.	Charcoal powder	0.64
Glass	7.	Straw chopped	0.56
Brick work	5.	Coal dust	0.54
Plaster	4.	Hemp canvas	0.41
Double windows	3.6	Muslin	0.40
Oak wood	1.7	Writing paper	0.34
Walnut wood	0.8	Cotton	0.32
Pine wood	0.75	Air confined	0.3
Sawdust	0.55	Gray blotting paper	0.27
India rubber	1.37		

saturating them. Very few of the materials used in practice for insulating walls, floors and ceilings are fireproof, and still fewer of these are moisture-proof, so the best insulator for the purpose might as well be selected. The comparative value of ordinary insulating materials, in terms of the heat transmitted through samples of the various materials of the same size and thickness, may be seen in Table XXIV. This

table gives the conducting power for each square foot of surface, and the comparative value is expressed in the number of units of heat lost per hour by transmission through them.

Tar paper, pitch, fine cinders, hair, felt, etc., are used with success.

One of the conditions to be taken into account in dealing with low temperatures is the facility with which moisture from the air will be absorbed by some of the insulating materials and lead to decay, softening the acid fermentation. For this reason granulated cork, pitch, tar paper, wood well shellacked, or substances which will resist moisture, are the favorites. Use only substances which have no strong odor or which have been deodorized.

In using cork or mineral wool, care must be taken to pack it carefully, otherwise it will settle and destroy the effect sought to be obtained.

Woodwork should be well nailed to prevent displacement under the effect of packing wool or cork.

Insulating Refrigeration Pipes.—Exposed ammonia suction pipes and brine pipes outside of cold-storage compartments or freezing tanks must be protected from the atmosphere, otherwise there will be a large transfer of heat from the rooms through which they pass to the cooling medium within, and the outside of the pipes will become covered with ice from the moisture condensing on them.

To thoroughly insulate refrigeration pipes it is necessary not only to keep heat from reaching them but also to keep out the moisture; consequently, the insulating materials used must be both heat proof

and water proof. There is no practical heat-insulating material in use at the present time which does not possess capillary attraction to a greater or less degree, so in insulating refrigeration pipes alternate layers of waterproofing materials and heat-insulating materials are used. The pipe insulating commonly used is made up into sections, the inner and outer sides of which are covered with waterproof paint, asphalt or some other good moisture-resisting material. For ordinary temperatures single thickness of insulating material, 1 inch thick, is used, and for very low temperatures double layers are recommended, care being taken to break the joints and seal the covering at the joints with waterproof cement. Some coverings are made in varying thicknesses from 1 inch to 3 inches, for use according to the size of pipe and temperature of the brine or ammonia.

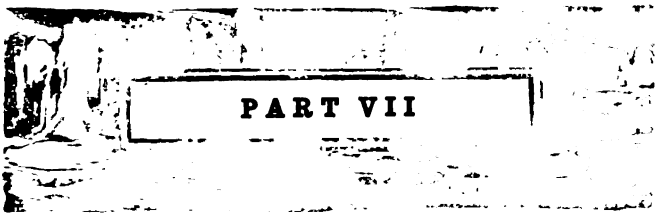
The most satisfactory materials for refrigeration pipe covering are granulated cork moulded into shape; wool felt and roofing felts, alternated with parchment paper; flax fiber with outer and inner layers of asphalt-saturated felt, and combination hair felt consisting of alternate layers of hair felt and waterproof asbestos or other waterproof material. When the sectional pipe covering is all in place and the joints all sealed with waterproof cement, it is well to cover the sectional covering with a waterproof and weatherproof jacket to keep moisture from creeping in anywhere.

The exposure of a building has a great deal to do with the quality and amount of heat insulation required. A building erected in a cool shady spot where evaporation is rapid, would not require as

much insulation as another building of like shape and dimensions erected on a hill top and exposed on all sides to the heat of the sun.

Again, a refrigeration building erected alongside of or against a power house or boiler room would require more and better insulation on the sides exposed to the heat than on the other walls of the building. In fact, each refrigeration building is a problem of itself in insulation, and must be worked out with full knowledge in mind of the exposures and the sources from which the greatest heat leakage will come.

The main thing to keep in mind is that good insulation at any cost is cheap. The insulation is paid for but once and that ends the matter. When insulation has been sparingly used, however, or inferior methods used, it will have to be paid for over and over again, every day so long as the plant is operated.



COLD-STORAGE ROOMS

CHAPTER XIII

REFRIGERATION REQUIRED FOR STORAGE ROOMS

CONDITION of Cold-Storage Rooms.—Temperature is not the only consideration in the cold-storage rooms of a refrigeration plant. Of course, the temperature is very important, as different products require different temperatures for their preservation, as may be seen in Table XIX. The air of the rooms and the amount of moisture in the air, however, play almost equally important parts in the preservation of the foodstuffs. If the air of the cold-storage rooms is too dry, evaporation will dry out the goods, not only reducing their commercial weight but spoiling their appearance, if not their substance. If, on the other hand, the air is too moist, mold might form on the

stored goods, and all the goods acquire a musty odor. Both the quality of the air in the cold-storage rooms and the amount of moisture it contains can be regulated by a suitable system of ventilation, hygrometers or psychrometers being used to ascertain the amount or relative humidity of the air, so the normal humidity can be maintained. The normal humidity of air is from 60 to 70 per cent. of saturation of the relative humidity. By relative humidity is meant the percentage of moisture contained in air in different temperatures. For example, at 10° Fahrenheit and 60 per cent. of saturation 1 cubic foot of air would contain .466 grain of water, while at a temperature of 70° Fahrenheit 1 cubic foot of air would hold 4.788 grains of moisture when containing 60 per cent. of saturation. The amount of water, it will be seen, varies thus with the temperature for certain percentages of saturation, and the amounts so contained at different temperatures, but the same percentage of saturation represents the relative humidity at different temperatures. The actual amount of moisture that air will hold depends upon its temperature. When the air is so charged that it will hold no more it is saturated, or contains 100 per cent. at that temperature. Adding more moisture to the air or lowering its temperature will cause a precipitation or condensation—as, for instance, in rain or dew, which are merely a precipitation of moisture due to over-saturation or fall in temperature. On the other hand, if air is saturated and its temperature is then raised the percentage of saturation falls and the air can absorb more moisture. The relative humidity of air at different temperatures can be found in Table XXV.

From the table it will be seen that if air is introduced to a building during ordinary summer weather of 80° Fahrenheit, when the humidity of the outside air is normal, or contains about 60 per cent. of moisture, 1 cubic foot of air at that temperature would contain

TABLE XXV

RELATIVE HUMIDITY OF AIR

Temperature Degree	Weight of Water in Grains per Cubic Foot of Air						
	Percentage of Saturation						
	40	50	60	70	80	90	100
—10	.114	.142	.171	.200	.228	.256	.285
— 5	.148	.185	.222	.259	.296	.333	.370
0	.192	.240	.289	.337	.385	.433	.481
+ 5	.244	.305	.366	.427	.488	.549	.610
10	.310	.388	.466	.543	.621	.698	.776
15	.394	.493	.502	.690	.789	.887	.986
20	.494	.618	.741	.864	.988	1.112	1.235
25	.620	.776	.931	1.086	1.241	1.396	1.551
30	.774	.968	1.161	1.354	1.548	1.742	1.935
35	.946	1.183	1.420	1.656	1.893	2.129	2.366
40	1.140	1.424	1.709	1.994	2.279	2.564	2.849
45	1.366	1.707	2.048	2.390	2.731	3.073	3.414
50	1.630	2.038	2.446	2.853	3.261	3.668	4.076
55	1.940	2.424	2.909	3.394	3.879	4.364	4.849
60	2.298	2.872	3.447	4.022	4.596	5.170	5.745
65	2.713	3.391	4.069	4.747	5.426	6.101	6.782
70	3.192	3.990	4.788	5.586	6.384	7.182	7.980
75	3.742	4.678	5.614	6.549	7.485	8.420	9.356
80	4.374	5.467	6.560	7.654	8.747	9.841	10.934
85	5.094	6.368	7.642	8.915	10.189	11.462	12.736
90	5.916	7.395	8.874	10.353	11.832	13.311	14.790
95	6.850	8.562	10.274	11.987	13.699	15.412	17.124
100	7.906	9.883	11.860	13.836	15.813	17.789	19.766
105	9.100	11.375	13.650	15.925	18.200	20.475	22.750
110	10.445	13.056	15.667	18.278	20.890	23.501	26.112
115	11.955	14.943	17.932	20.921	23.910	26.898	29.887
120	13.646	17.057	20.468	23.880	27.880	30.703	34.115

6.560 grains of water. When this cubic foot of air is lowered in temperature to 20° Fahrenheit, however, it will require only .741 of a grain of moisture to keep it at the relative and normal humidity of 60 per cent. saturation.

The difference between 6.560 and .741, or 5.819 grains of water, will then be deposited on the walls, floor, coil of pipes or stored products, from every cubic foot of air within the enclosure.

Refrigeration Required for the Cold-Storage Rooms.—The refrigeration required for cold-storage rooms may be divided into two parts—that required to keep the rooms at their right temperatures, withdrawing the heat leaking into the enclosure through the walls, floors and ceilings, and that required to cool the products stored in the rooms from their temperatures when brought into the compartment to that of the rooms.

In large cold-storage warehouses containing 250,000 cubic feet or more of storage space, well insulated and properly constructed, one ton of refrigeration is considered capable of maintaining 10,000 cubic feet of space at a temperatore of 30° Fahrenheit, plus 5,000 cubic feet of space at a temperature of 15° Fahrenheit; or one ton of refrigeration will maintain either 20,000 cubic feet of space at 30° temperature, or 10,000 cubic feet of space at freezing temperature. In small cold-storage warehouses of from 50,000 to 100,000 cubic feet of storage space one ton of refrigeration is considered capable of maintaining 6,000 cubic feet of space at cold-storage temperature, plus 3,000 cubic feet of space at freezing temperature, or it will maintain either 6,000 cubic feet of space at freezing temperature, or 12,000 cubic feet of space at cold-storage temperature. The foregoing ratings apply only to the enclosures, however, to remove the heat leaking into the storage rooms. They do not

include the refrigeration required to cool the products to be stored.

The refrigerating effort in B. T. U. required to keep the storage rooms at constant temperature can be computed by means of the following rule:

RULE.—To find the number of British thermal units to be withdrawn in order to maintain a constant temperature in the storage rooms, multiply the area in square feet of floor, wall and ceiling space by the constant 3, and the product by the number of degrees the rooms are to be lowered in temperature.

Expressed as a formula:

$$H = 3A\ (T—t).$$

In which:

H = number of B. T. U. of refrigeration effort required.

A = area of walls, floors and ceilings in square feet.

T = temperature of adjoining compartments or outside air.

t = temperature to be maintained in the cold-storage rooms.

3 = a constant for leakage of heat through walls.

EXAMPLE.—How many B. T. U. of refrigeration will be required for a cold-storage room 40 x 50 x 12 feet in dimensions to keep it at a temperature of 35° Fahrenheit where the outside temperature is 70° Fahrenheit?

SOLUTION.—

Area of wall surface, $40 + 40 + 50 + 50 \times 12$ =	2,160
Area of floor and ceiling, $40 \times 50 \times 2$ = .	4,000
Total area, square feet, ...	6,160

Temperature outside, 70° Fahrenheit.
Temperature inside, 35° Fahrenheit.

Difference in temp., 35° Fahrenheit.

Substituting these values in the formula, H = 3 × 6160 × 35 = 646,800 B. T. U. (Answer.)

There are 285,300 B. T. U. to one ton of refrigeration, so to reduce the British thermal units to tons all that is necessary is to divide by that number. Applying this principle to the foregoing solution, 646,800 ÷ 285,300 = 2.23 tons. Checking this answer to the example given with the empirical formula of allowing one ton refrigeration to 12,000 cubic feet of space, it will be seen that the formula is perfectly safe, as it provides for slightly greater horsepower than the empirical rule does. Instead of first finding the number of B. T. U. and then dividing them by 285,300 to find the tons of refrigeration required, the tonnage can be ascertained in one transaction by converting the B. T. U. into the decimal .000003505 and multiplying the other quantities with it. Expressed as a formula this would then be:

$$P = .000003505 \times 3A\ (T—t).$$

In which:

P = refrigeration tonnage.

3 = constant for heat leakage in wall surface.

A = Area in square feet of walls, floors and ceilings.

T = outside temperature of cold-storage rooms.

t = inside temperature of cold-storage rooms.

EXAMPLE.—From the preceding example find the number of tons refrigeration by the present formula.

SOLUTION.—Substituting the values found in the formula, then, P = .000003505 × 3 × 6160 × 35 = 2.23. (Answer.)

In applying the foregoing rules and formulas judgment must be exercised the same as when applying any rule or formula in engineering practice. If, for instance, the cold-storage compartments, or the building in which they are in are not well insulated, or well built, or for any other reason there would be a liability of excessive heat leakage, an extra allowance should be made to offset the loss.

Refrigeration Required to Cool Stored Goods.—The refrigerating effort in B. T. U. required to cool stored products from their ordinary temperatures to that of the cold-storage rooms can be found by the following rule:

RULE.—Multiply the weight of the goods by their specific heats, and the product by the difference between the ordinary heat of the stored goods and the temperature of the storage rooms.

Expressed as a formula:

$$H = W\ S\ (T—t).$$

In which:

H = number of B. T. U. of refrigeration effort required.

W = weight of stored goods.

S = specific heat of stored goods.

T = temperature of goods when put in storage.

t = temperature of cold-storage rooms.

When several different kinds of goods are stored, each kind of goods having a different specific heat,

then the sums of all their various weights and specific heats would be required, and the formula would be:

$H = WS + W_1S_1 + W_2S_2 (T—t)$, in which the WS, W_1S_1, W_2S_2, etc., refer to the different goods, such as WS would equal the weight times specific heat of beef; W_1S_1 the weight plus specific heat of pork; and W_2S_2 the weight plus the specific heat of veal.

The specific heat of various goods placed in cold storage are given in Table II.

EXAMPLE.—Find the refrigeration required to cool 25,000 pounds of lean beef from a temperature of 95° Fahrenheit to 35°.

SOLUTION.—In Table II it will be seen that the specific heat of beef above the freezing point is .77, and the difference in temperature between 95° and 35° = 60°. Substituting the given values in the formula, then, H = 25,000 × .77 × 60 = 1,155,000 B. T. U. (Answer.)

By dividing the number of B. T. U. by 285,300, the number of B. T. U. in a ton of refrigeration, the answer will be the tons of refrigeration required. Thus, 1,155,000 ÷ 285,300 = 4.05 tons. (Answer.) Instead of dividing by 285,300 the B. T. U. may be multiplied by the decimal of that number, and the answer will be the same. Thus, 1,155,000 × .000003-505 = 4.05 tons. (Answer.)

EXAMPLE 2.—What tonnage of refrigeration will be required to cool from 95° Fahrenheit to 35° 16,000 pounds of pork; 10,000 pounds of poultry; 22,000 pounds of fat beef, and 6,000 pounds of veal?

SOLUTION.—Difference in temperature (T—t) = 95—35 = 60. From Table II it will be seen that the specific heat of pork above freezing is .51; of poultry .80; of fat beef .60, and of veal .70. Substituting these values in the formula,

P = .000003505 (16,000 × .51 + 10,000 × .80 + 22,000 × .60 + 6,000 × .70 (60) = 7.06 tons). (Answer.)

When calculating the amount of refrigeration that will be required for a cold-storage room, the amount necessary to keep the temperature of the room at the right degree must be added to the amount necessary to cool the products stored in the room.

As was pointed out in the Principles of Refrigeration, work is independent of time, no consideration being given to whether it takes one minute or one year to perform it; but, in order to compare with a common standard the work done by different machines, time must be considered. Therefore, in calculating the amount of refrigeration that will be required for a cold storage room, the length of time in which the coils must abstract the heat must be taken into consideration. This calculation may be divided into two parts. One the amount of refrigeration working continuously that will be required to keep the enclosure at the right temperature, and the other, the amount of refrigeration that will be required to reduce the temperature of the stored products to the right degree in a certain specified period of time.

In making allowance for the refrigerating effort required to cool the products stored in refrigerating compartment, the maximum allowance must be

made to take care of the greater amount of materials ever likely to be stored, and materials of the greatest specific heat must be assumed so there will be enough coil surface, and capacity in the entire plant to do the work it is designed for. As was previously pointed out, the cooling coil surface is easily taken care of by breaking the total coil surface up with a series of units which can be thrown in or out of service at will. This will take care of the actual heat abstracting surface, then the compressor if large enough for the maximum load will take care of any lighter load by reducing the speed, while the condensers are, like the cooling coils, in batteries which can be cut out or thrown in use at will.

PART VIII

AUXILIARY COOLING SYSTEM

CHAPTER XIV

BRINE-CIRCULATING SYSTEMS

APPLICATION of Brine Circulation Systems.—The brine-circulation system used in refrigeration is only part of a refrigeration plant, and must be used in connection with either the compression system of refrigeration or with the absorption system. The brine system is in no way connected with the production of cold, only with its distribution, therefore it is not a refrigeration system. To explain the brine-circulation system, it will be necessary to treat it in connection with a refrigeration system, so we will refer back to the direct expansion system shown in Fig. 5. If in this illustration the expansion coils shown on the walls of the cold-storage room were immersed in a large iron or steel tank containing brine, the refrigeration part of a brine circulation

system would be had. Referring now to Fig. 55, the brine circulation part of the system can be seen. The brine tank is filled with a solution of strong brine made from common salt or from calcium chloride, enough being used to completely submerge the ammonia expansion coils when the brine tank is full. The ammonia coils are shown inside the tank. These are the coils that would be located in the cold-storage rooms in the direct-expansion system of refrigeration.

The liquid ammonia evaporating in these coils can do so only by the absorption of heat, and this heat is supplied by the pipes and fittings of the coils, which, being thus lowered in temperature, draw in turn upon the heat of the brine in the tank. The brine being thus robbed of its heat, there becomes stored in the tank a large supply of what might be termed "cold," or refrigerating effort. To utilize this cold it must be circulated through the cold-storage rooms (except in ice making, which will be explained later), and this can be done only by means of a circulating pump. From the bottom of the tank then, where the coldest brine will be found, the pump draws its supply, forces it through the coils, and back again to the brine tank to be again cooled and circulated. This in simple is the brine circulation system of cooling.

Advantages of the Brine System.—The cooling of cold-storage rooms by the circulation of cold brine has the following advantages over the direct expansion system. In the first place, less ammonia will be required to charge the brine system than the direct-expansion system, because there is but the one battery of coils to fill in the brine circulation system,

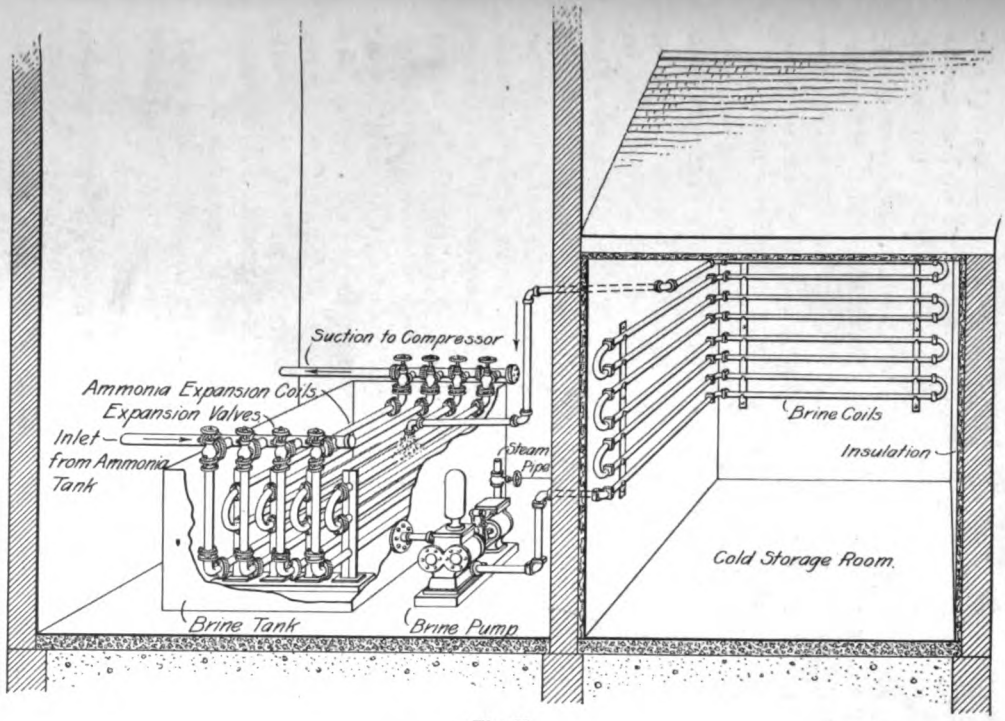


Fig. 55
Brine System of Cooling

whereas there might be several times the amount of pipe coils in an equal size direct-expansion system.

The cutting down of the amount of ammonia used has additional advantages in that it decreases the possibility of leaks, and should leaks occur they will be outside of the storage rooms, where they might damage the stored goods. By using the brine-circulation system the machinery and all of the refrigeration part of the system can be compactly arranged in the engine-room, convenient for the engineer.

In the direct-expansion system the refrigerating effect ceases upon the stoppage of the compressor. In the brine system, on the other hand, the large body of the chilled brine contained in the brine tank and pipe coils is a storage of cold, and is a reserve that can be called upon to maintain the temperature desired in the rooms for a considerable length of time, when necessary to stop the compressor, by merely operating the brine-circulating pump. By putting in a large brine tank, in many cases it will be found necessary to operate the compressor only during the daytime to maintain the right temperature in the storage rooms during the twenty-four hours of a day.

Advantages of the Direct-Expansion System.—In the direct-expansion system the expense of the installation is greatly reduced as compared with the brine system, the brine tank, brine pump and secondary system of pipes for brine circulation being dispensed with and a somewhat greater efficiency obtained. Owing to the lower temperature of the expanding ammonia in the direct expansion system and the greater rapidity of the circulating gas, only

about two-thirds the amount of pipe surface is required in the cold-storage rooms as are required to produce the same effect with brine pipe coils. The ammonia is expanded at a much higher temperature and pressure, and is therefore drawn back to the compressor at higher density, resulting in the machine circulating a much greater weight of ammonia per minute. Each pound of ammonia has just as much potential refrigerating energy and the capacity of a compressor is therefore dependent solely upon the weight of ammonia pumped in a given time. For example, if it is desired to maintain a temperature of 32° F. in a certain room, it will require a compressor displacement of about 22 per cent. more with the brine system than with direct expansion.

Again, there is of necessity a large surface to a brine tank, and no matter how well insulated the tank may be, more or less loss due to absorption of heat will be experienced.

To sum up the difference between the two systems, it might be said that the direct-expansion system is the less expensive in first cost, more simple in operation and less expensive to operate. Owing to these reasons, save in exceptional cases, the direct-expansion system is employed almost exclusively in refrigerating plants which are operated continuously.

Brine Tank Insulation.—It is absolutely necessary that the brine tank be thoroughly insulated, or with so large a surface exposed there will be a great loss of cold, even though the loss per square foot of surface be kept very low. One method of insulating a brine tank is shown in Fig. 56. It is simply the

application of air spaces, pitch and insulating filling materials to the ice box, the same as for walls, ceilings and floors of the cold-storage rooms. For filling material, cork board, mineral wool, charcoal or any of the insulating materials previously mentioned may be used.

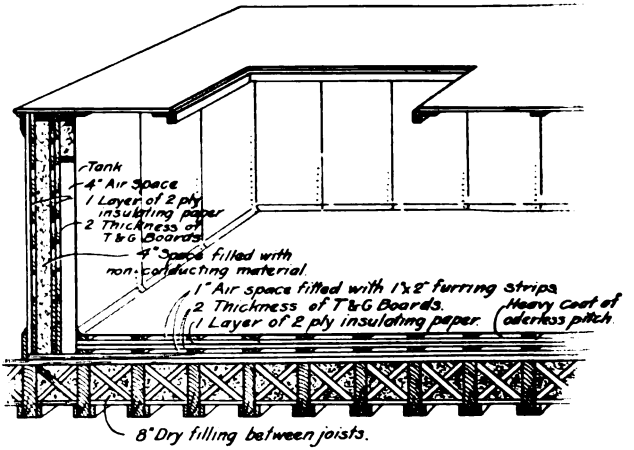

Tank
4" Air Space
1 Layer of 2 ply insulating paper
2 Thickness of T&G Boards
4" Space filled with non-conducting material
1" Air space filled with 1"x2" furring strips
2 Thickness of T&G Boards.
1 Layer of 2 ply insulating paper.
Heavy coat of odorless pitch
8" Dry filling between joists.

Fig. 56
Brine Tank

Double-Pipe Brine Coolers.—Instead of using brine tanks, double-pipe brine coolers or triple-pipe brine coolers may be used to cool the brine, thereby having an entirely closed system throughout the plant. The double-pipe brine cooler of the counter-current type is shown in Fig. 57. These coolers differ but slightly from ammonia condensers, the greatest difference being in the size of pipe used, which in the brine coolers is larger than in the condensers. In the brine coolers the diameter of the inside pipes is commonly 2 inches and that of the outer pipe 3 inches.

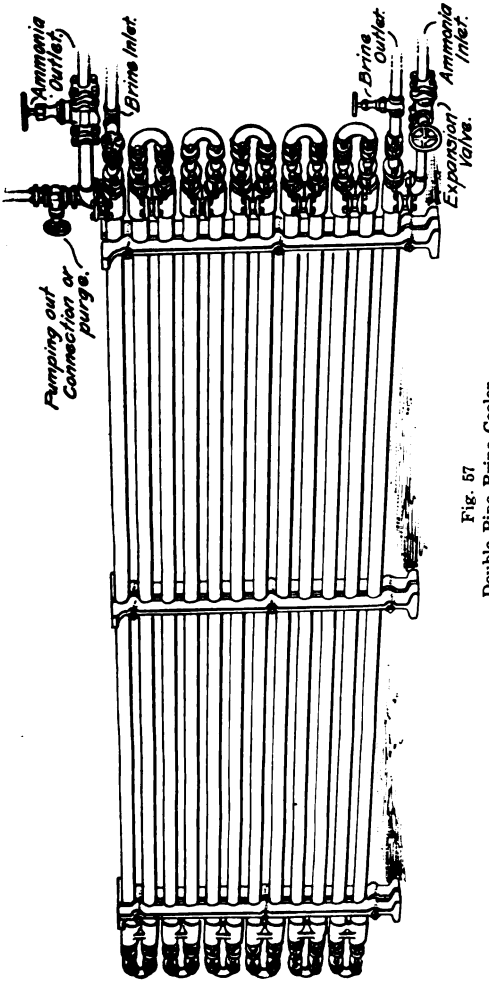


Fig. 57
Double Pipe Brine Cooler

The ammonia is allowed to expand in the annular space between the inner and the outer pipes, while the brine circulates through the inner system of pipes. The ammonia enters the coil at the bottom and is drawn back to the suction side of the compressor from the top of the coil. Brine, on the other hand, enters the top round of the coil where it is in contact with the warmest ammonia pipes, and flows from the outlet at the bottom, where it leaves the cooler while in contact with the coldest ammonia pipe surface.

The approximate sizes, weights and capacities of double-pipe brine coolers can be found in Table XXVI.

TABLE XXVI

SIZE AND CAPACITY OF DOUBLE-PIPE BRINE COOLERS

Diam. of Inside Pipe Inches	Diam. of Outside Pipe Inches	Capacity Tons Refrigerat'n	No. of Pipes in Height 6-in. Ctrs.	Length Over All Feet	Shipping Weight
2	3	2½	2	18	650
2	3	5	4	18	1,175
2	3	7½	6	18	1,700
2	3	10	8	18	2,225
2	3	12½	10	18	2,750
2	3	15	12	18	3,325

Some double-pipe brine coolers are made of smaller pipe—1½-inch pipe being used for the inner coils and 2-inch pipe for the outer coils.

Double-pipe brine coolers and triple-pipe brine coolers are covered in practice with some good insulating material to prevent absorption of heat from the atmosphere and surrounding objects. Sometimes double-pipe brine coolers are used in connection with brine tanks, thereby utilizing the cooling effect of the expanding ammonia on the outside of the coils. A double-pipe brine cooler in a brine tank is shown in Fig. 58.

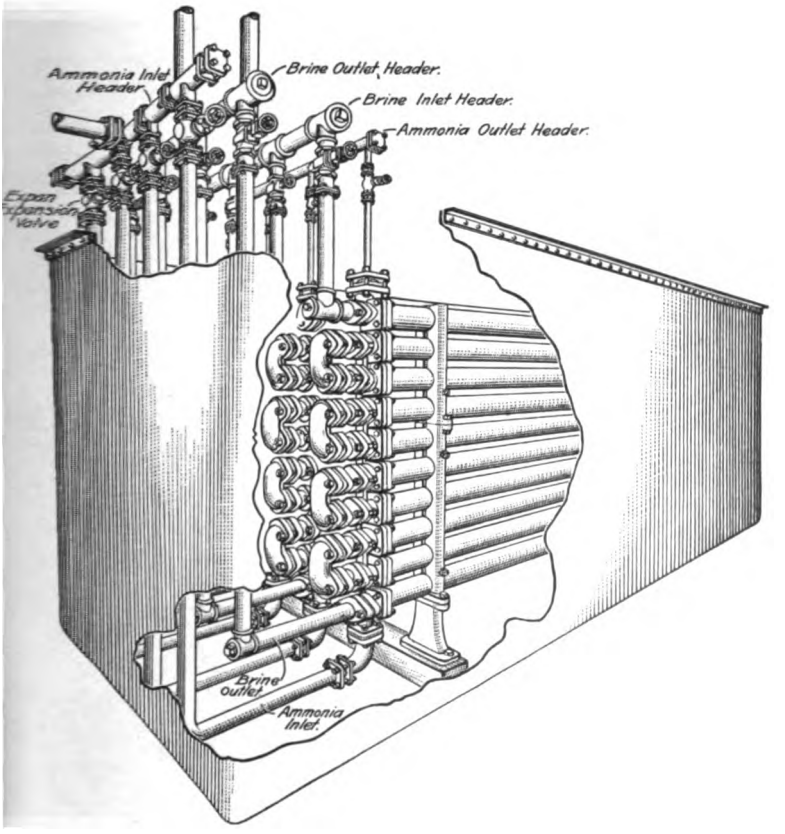


Fig. 58
Double Pipe Brine Cooler in Brine Tank

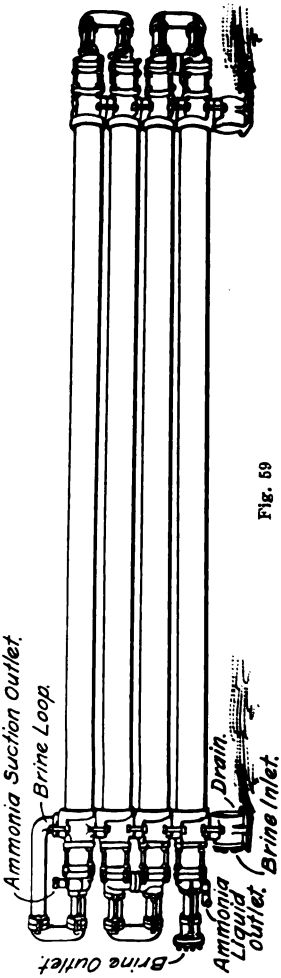


Fig. 59
Triple-pipe Brine Cooler

The usual method of operating an apparatus of this kind is to connect the pump so as to take the brine from the tank, force it through the inner pipes of cooler, thence to the rooms to be refrigerated, and after performing such duty to return to the tank. This method insures cold temperatures almost as soon as the plant is started, whereas the system of cooling a large body of brine in a tank takes a much longer time.

Triple-Pipe Brine Cooler.—From the submerged double-pipe brine cooler to the triple-pipe brine cooler was but a step whereby providing a third space for brine to circulate in, the cooling effect of the expanding ammonia on the outside of the pipe forming the central compartment could be utilized and the entire system still be a closed circuit. A three-pipe brine cooler is shown in Fig. 59. The liquid ammonia enters the intermediate pipe at the bottom, where it is released from pressure and flashes into a gas, drawing upon the walls of the pipes and the brine circulating through them for the heat necessary for vaporization. The brine enters the outside coil of pipe at the bottom, passes successively through the various loops of the coil to the top, where by means of the brine loop it is connected to the central pipes of the coil, down which it passes to the outlet at the bottom. Chloride of calcium brine is preferable for use in a plant where a triple-pipe brine cooler is used, owing to its lower freezing point than salt brine and not precipitating at the low temperatures. Like the double-pipe brine cooler, the triple-pipe brine cooler should be insulated unless located in an insulated

cold-storage room, where it may be left uninsulated, and the cold from the outer coils will help maintain the temperature of the room.

When double-pipe or triple-pipe brine coolers are used there is no storage of cold like when a brine tank is installed, for the brine in a closed-pipe brine cooler system is comparatively so small a quantity that the refrigerating effect ceases almost as soon as the compressor is shut down. On the other hand, pipe-brine coolers are less expensive to operate on account of a lower temperature of brine being possible, consequently less pumping.

PROPERTIES OF BRINE

SALT Brine.—The brine used in a refrigeration system must be kept at a certain degree of concentration to obtain the most economical operation. The specific heat or capacity for heat of salt water is considerably less than for ordinary water and decreases as the solution becomes stronger. For example, a certain weight of ordinary water when its temperature is raised a certain number of degrees will abstract more heat than an equal weight of brine if raised the same number of degrees in temperature; and the stronger the brine the greater will be this difference between the capacities for heat. As an agent for transmitting cold .8 pound of ordinary water will do the same service as 1 pound of brine of 1.186 specific gravity, which has a freezing point of slightly over 1° Fahrenheit. Water, then, would be a better medium for the transmission of cold than brine, only the water freezes at too high a temperature to be of practical use, so that brine must be used in its stead.

As the stronger the brine is the less its capacity to transmit cold, it stands to reason that solutions of salt for refrigerating purposes should not be made any stronger than is necessary to keep them from freezing. The freezing points of brine solutions, strength of solution and other properties can be found in Table XXVII.

From the table it will be seen that brine having 5 per cent. of salt by weight will freeze at a temperature of 25.4° Fahrenheit. If the temperature of the brine will not be required lower than 26° or 27°, a 5 per cent. solution would be sufficient. If a temperature of 19° or 20° must be maintained, a solution of 10 per cent. strength should be used. The aim would be, of course, to make the solution strong enough not to freeze and at the same time weak enough to be a good medium for the transmission of cold.

The table contains no stronger solutions than 25 per cent. This is because that is the greatest amount of salt the brine will hold in solution at a temperature of 0° Fahrenheit.

The strength of brine can be readily ascertained by means of a salometer, an instrument similar to the hydrometer, shown in Fig. 2, but graduated for liquors heavier than water. By referring to the table the degrees shown on the salometer can be converted into percentage of salt. Salt is cheaper in first cost than chloride of sodium, but has a corrosive effect on iron. Care should be exercised to select a good salt for brine making, as ordinary desert salt is unsuitable for the purpose, it containing so many impurities that it does not give a strong solution.

TABLE XXVII

PROPERTIES OF SALT SOLUTIONS—(CHLORIDE OF SODIUM—COMMON SALT)

Perc'tg of Salt by Wgt.	Degs. on Salometer at 60° F.	Specific Gravity of 60° F.	Specific Heat	Weight One Gal. Gallon	Lbs. of Salt in One Gal.	Lbs. of Water in One Gal.	Wgt. of One Cubic 1 Cu. Ft.	Lbs. of Salt in 1 Cu. Ft.	Lbs. of Water in 1 Cu. Ft.	Freezing Point, Degs. F.
0	0	1.	1.	8.35	0.	8.35	62.4	0.	62.4	32.
1	4	1.007	0.992	8.4	0.084	8.316	62.8	0.628	62.172	31.8
5	20	1.037	0.96	8.65	0.432	8.218	64.7	3.237	61.465	25.4
10	40	1.073	0.892	8.95	0.895	8.055	66.95	6.695	60.253	18.6
15	60	1.115	0.855	9.3	1.395	7.905	69.57	10.435	59.134	12.2
20	80	1.150	0.829	9 6	1.92	7.68	71.76	14.352	57.408	6.86
25	100	1.191	0.783	9.94	2.485	7.455	74.26	18.565	55.695	1.00

Calcium Chloride Brine —Chloride of calcium, owing to its lower freezing point, has a wider range of usefulness than has common salt brine. Whereas common salt brine of 25 per cent. strength

TABLE XXVIII

PROPERTIES OF CHLORIDE OF CALCIUM SOLUTIONS

Specific Gravity at 64° F.	Degree Beaume at 64° F.	Degree Solometer at 64° F.	Per Cent. of Calcium Chloride	Freezing Point in Degrees F.	Ammonia Guage Pressure Pounds per Sq. Inch
1.007	1	4	0.943	+31.20	46
1.014	2	8	1.886	+30.40	45
1.021	3	12	2.829	+29.60	44
1.028	4	16	3.772	+28.80	43
1.035	5	20	4.715	+28.00	42
1.043	6	24	5.658	+36.89	41
1.050	7	28	6.601	+25.78	40
1.058	8	32	7.544	+24.67	38
1.065	9	36	8.487	+23.56	37
1.073	10	40	9.430	+22.09	35.5
1.081	11	44	10.373	+20.62	34
1.089	12	48	11.316	+19.14	32.5
1.097	13	52	12.259	+17.67	30.5
1.105	14	56	13.202	+15.75	29
1.114	15	60	14.145	+13.82	27
1.112	16	64	15.088	+11.89	25
1.131	17	68	16.031	+ 9.96	23.5
1.140	18	72	16.974	+ 7.68	21.5
1.149	19	76	17.917	+ 5.40	20
1.158	20	80	18.860	+ 3.12	18
1.167	21	84	19.803	— 0.84	15
1.176	22	88	20.746	— 4.44	12.5
1.186	23	92	21.689	— 8.03	10.5
1.196	24	96	22.632	—11.63	8
1.205	25	100	23.575	—15.23	6
1.215	26	104	24.518	—19.56	4
1.225	27	108	25.461	—24.43	1.5
1.236	28	112	26.404	—20.29	1" vacuum
1.246	29	116	27.347	—35.30	5" "
1.257	30	120	28.290	—41.32	8.5" "
1.268	31	...	29.233	—47.66	12" "
1.279	32	...	30.176	—54.00	15" "
1.290	33	...	31.119	—44.32	10" "
1.302	34	...	32.062	—34.66	4" "
1.313	35	...	33.000	—25.00	1.5 pound

freezes at about zero temperature, chloride of calcium brine will resist a much lower temperature—50° below zero being the limit. The properties of chloride of calcium solutions from percentages of .943, with

corresponding freezing point of +31,20, to solutions of 33 per cent. strength, with freezing temperature of 25° below zero, can be found in Table XXVIII.

Chloride of calcium has no corrosive effect on iron, therefore the brine pump need not be lined with brass. Instead of being a corrosive it is of an oily nature, and for this reason has a strong tendency to leak if the joints in the brine coils are not perfectly tight.

Size of Brine Coils.—The brine coils in cold-storage rooms differ but little from direct-expansion ammonia coils when used for the same purpose. Instead of ammonia pipes and fittings, ordinary steam and water pipes and fittings may be used for brine circulation, but a larger allowance of surface must be made to offset the lower temperature of the brine system. Small brine coils are more economical in operation.

If there is but one-half the pipe surface required, the brine must travel at double the velocity to pass the required quantity into the room in a given time. And this is not all: each square foot of pipe surface will transmit or conduct to the brine just so much heat, and time of contact is an element; further, the larger the body of brine contained in the coils in any room, and the longer in transit, the less friction in moving it, the more effective the cooling surface, and the greater the possible range of temperature between the outgoing and return brine. When the pipe surface is reduced beyond a certain point, the brine has to be made very much colder (which is not economical) to create a greater difference of temperature between the

inside and outside of pipe, in order that it may take up the required heat. The transmitting efficiency of pipe increases with the difference in temperature without regard to time. Again, an inadequate amount of pipe surface will not allow a rise of temperature in the brine tank without the rooms thus insufficiently piped becoming too warm, no matter how fast the brine pump is run.

Owing to the lower temperature and greater rapidity of the circulation of ammonia gas only about two-thirds the pipe surface is necessary in a direct-expansion ammonia coil to produce a given refrigerating effect as would be required in a brine coil.

In the brine system 800 feet of 1¼-inch pipe is as much as can be properly worked in one coil. This limit, however, is seldom used, for the size of the coil is generally proportioned to the temperature required. When a very low temperature is required the coils would have to be shortened, for as the ammonia does not evaporate rapidly enough in very cold brine too much liquid would be trapped in long coils. Ordinarily, the brine-pipe system is divided into coils or sections containing not more than 400 feet of 1-inch pipe or its equivalent in other sizes, and so connected to the mains that each section can be cut off independently of the others. Pipes of from 1 inch to 2 inches in diameter are generally used for the brine coils.

Making a Calcium Chloride Solution.—All that is necessary in making a calcium chloride brine is to dump the right amount of the chloride of calcium in the brine tank, near the pump suction, then start the pump working. The affinity of this salt for water

is so great that it will readily dissolve, even when the brine is at a comparatively low temperature, and the agitation of the contents of the tank by the operation of the pump will insure a uniform mixture. The amounts of chloride of calcium required from salometer and Baumé readings, together with the freezing points of the different strengths of solution, can be found in Table XXIX.

TABLE XXIX

PROPORTIONS FOR MAKING CALCIUM BRINE

Pounds Chloride of Calcium (Commercial fused) to One	Degrees Salometer 60° F.	Degrees Baumé 60° F.	Freezing Point Degrees F. Gallon of Water
2½	80	20	4
3	88	22	— 2
3½	96	24	— 9
4	104	26	—17
4½	112	28	—27
5	120	30	—39
5½	...	32	—54

Whether calcium chloride or salt is used for the solution, samples of the brine should be taken out occasionally and tested with a hydrometer, until the right gravity is reached. Should too much salt be added to the solution it can be weakened by adding more water to the brine in the tank.

Making a Salt Solution —The brine used in refrigeration practice is generally made from common salt. About 2½ pounds of salt per gallon of water will make brine of 100° density on salometer, which will not freeze at 0° Fahrenheit. If a temperature below zero is required, chloride of calcium is used. The proportions of common salt required to make brine of different densities and freezing points have

already been given in Table XXVII. Salt will not dissolve as readily as chloride of calcium, therefore it is not practical to empty it in the tank depending on the brine to dissolve and take it in solution. The better way is to place the salt in a temporary crib, suspended in the brine tank, and have the discharge from the brine pump empty on the salt in this crib.

When it is desired to change the brine solution from salt to chloride of calcium, or from calcium chloride to salt, empty the tank of the one solution before filling it with the other. Never mix the two salts for any purpose. If chloride of calcium be added to a salt solution, the calcium will readily dissolve, but as it has a greater affinity for water than salt has, it will precipitate the salt out of the brine, and possibly clog some of the pipes in the system.

Brine Pump.—With but one limitation, any good steam pump, single or duplex, may be used as a brine pump. That one limitation has reference to a brine pump for pumping chloride of sodium, or common-salt brine. Owing to the corrosive nature of salt brine, a pump for this fluid ought to be bronze lined throughout. That is, it should have a bronze cylinder, piston rod, and glands on the stuffing boxes. The valves and other parts which come in contact with the brine ought likewise to be made of non-corrodable materials.

If chloride of calcium brine is to be used bronze linings are not necessary, although probably desirable for there is no telling when for one reason or another a salt solution might be substituted for the chloride of calcium brine.

The pressure or head against which a brine pump has to work is comparatively low, and the ordinary low-service or tank pump is the type commonly used. The maximum piston speed at which the pump can run is 60 feet per minute, and the average speed is 40 feet per minute. In calculating the size of pump, then, a piston speed of 40 feet per minute, should be assumed.

In determining what size of brine pump will be required, the following data are commonly used:

One ton of refrigeration (not ice making) effort per twenty-four hours, is equal to, or will cool 25 gallons of brine 1° in one minute. But the sum of gallons and degrees is met in equal tonnage. That is, if 25 gallons of brine cooled 1° in one minute equals 1 ton of refrigerating effort, then 1 gallon cooled 25° in one minute, 5 gallons cooled 5° in 5 minutes, 12½ gallons cooled 2° in 1 minute, or any other like combination would be equal to 1 ton of refrigerating effort.

If, then, it is desired to select a brine-pump for a plant having a capacity of 15 tons a day, and the difference in temperature between the brine entering and leaving the brine tank is 6° Fahrenheit, a pump of 62 gallons capacity per minute would be required.

Brine Mains.—The brine mains must be of sufficient capacity to take care of the brine discharge by the brine pump, when the water is flowing at a sufficiently low velocity as not to require too much friction head. A velocity of about 10 feet per second would perhaps be a fair average. The size of the brine main, then, will depend upon the total refrigerating capacity of the plant. The initial and terminal

temperatures having been decided upon, 25, divided by the difference between initial and terminal temperatures will give the quantity of brine to be conducted per ton of refrigerating effort. This multiplied by the total tonnage will give the total volume of brine to be conducted, while multiplied by the tonnage of any section to be cooled will give the quantity of brine required to refrigerate that space.

In laying out the brine circulation system to various compartments, it is very important to distribute the flow of brine in such a way that the quantity sent to each portion will return at nearly the same temperature as the return from all the other parts. This will be difficult of accomplishment if the pipes are improperly proportioned, for in such case those circuits having large enough pipes would circulate the bulk of the brine at the expense of those circuits having too small pipes.

The diameter of a pipe required to discharge a given quantity of water or brine can be found by the formula:

$$d = .234 \sqrt[5]{\frac{q^2 l}{h}}$$

in which

d = diameter of pipe in feet.
q = cubic feet to be delivered per second.
l = length of pipe in feet.
h = head in feet.

Equation of Pipe.—In pipe fitting practice errors are often made, due to a misunderstanding of the comparative capacities of pipes of standard sizes. For instance, in Table XXX is shown the number of

TABLE XXX

NUMBER OF TIMES THE AREA OF ONE PIPE IS CONTAINED IN THAT OF A LARGER

	⅛	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6	7	8	9	10
⅛	1.																		
¼	1.9	1.																	
⅜	3.3	1.8	1.																
½	5.3	2.9	1.5	1.															
¾	9.3	5.2	2.7	1.7	1.														
1	14.7	7.7	4.1	2.6	1.6	1.													
1¼	26.2	14.3	7.8	4.9	2.8	1.6	1.												
1½	35.6	19.5	10.6	6.6	3.8	2.4	1.3	1.											
2	58.6	32.2	17.5	11.0	6.9	3.9	2.2	1.6	1.										
2½	83.6	44.6	25.0	15.7	9 0	5.5	3.2	2.3	1.4	1.									
3	129.1	71.0	38.5	24.2	13.8	8.5	5.0	3.6	2.2	1.5	1.								
3½	172.8	95.0	51.6	32.4	18.5	11.4	6.6	4.8	2.9	2.0	1.3	1.							
4	222.5	122.3	66.4	41.7	23.8	14.7	8.5	6.2	3.8	2.6	1.7	1.3	1.						
5	349.4	192.0	104.3	65.6	37.4	23.1	13.3	9.8	5.9	4.1	2.7	2.0	1.5	1.					
6	505.0	277.5	150.7	94.7	54.1	33.4	19.3	14.1	8.6	6.0	3.9	2.9	2.2	1 4	1.				
7	677.2	372.1	202.2	127.0	71.3	44.9	25.9	19.0	11.5	8.1	5.2	3.9	3.0	1.9	1.3	1.			
8	878.3	480.7	261.2	164.1	93.8	58.0	34.5	24.5	14.9	10.4	6.7	5.0	3.9	2.5	1.7	1.3	1.		
9	1112.4	611.2	332.1	208.7	179.3	73.4	42.7	31.2	19.0	13.3	8.7	6.4	5.0	3.1	2.2	1.6	1.2	1.	
10	1378.3	757.3	411.5	258.6	147.8	91.3	52.7	38.6	23.5	16.5	10.6	7.9	6.2	3.9	2.7	2.0	1.5	1.2	1.

times the area of one pipe is contained in that of another. If the seventh column headed 1 is followed down until it intersects the ninth item in the first column marked 2, it will be seen that the area of a 1-inch pipe is contained in that of a 2-inch pipe 3.9 times. For practical purposes this is taken as 4 times, and has given rise to the statements that doubling the diameter of a pipe increases its *area* four times, which is true, or, as sometimes expressed, that doubling the diameter of a pipe increases its *capacity* four times, which is not exactly true. At the same velocity of flow doubling the diameter of a pipe increases its capacity four times, but the same head or pressure will produce different velocities in pipes of different sizes or lengths, and doubling the diameter of a pipe when the pressure remains constant increases the capacity of the pipe about six times, the difference being unusually stated to vary as the square root of the fifth power of the diameter. It would follow from the foregoing that a brine main of large diameter would supply a greater number of small mains than combined would equal in area the area of the brine main, for the pressure in the system would be constant throughout. In Table XXXI will be found the equations of standard steam and water pipes, also of pipes having actual areas equal to the diameter stated.

Table XXXI is used in the following manner: If it is desired to know the number of $\frac{3}{4}$-inch pipes that will equal in discharging capacity a 2-inch pipe, glance down the column marked 2 to the intersection of the line in the first column marked $\frac{3}{4}$. This shows that it requires fourteen $\frac{3}{4}$-inch taps or pipes to equal one

TABLE XXXI

EQUATION OF PIPES—STANDARD STEAM AND GAS PIPES

Dia. In.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia. In.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488	3,014	3,786	4,904	5,927	7,321	8,535	9,717	½
¾	2.60		2.05	6.97	14.0	23.5	42.5	90.4	166	273	405	569	779	1,096	1,328	1,668	2,161	2,615	3,226	3,761	4,282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1,070	1,263	1,576	1,837	2,092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	84.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.33	15
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20,327	7,810	2,691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26,676	10,249	3,532	1,102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42,621	16,376	5,644	1,761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249,351	95,818	33,020	10,301	4,554	2,431	1,465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia. In.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia. In.

2-inch pipe. To find the number of pipes of one size that equals the discharging capacity of another, in the lower part of the table, follow down the columns the size of the smaller pipe until it intersects the line of the larger one. Thus, to find the number of 2-inch pipes that equal a 10-inch pipe, follow down the column marked 2 to where it intersects the line marked 10 and it will be found that 80.4 2 inch pipes equal in discharging capacity one 10-inch pipe.

CARBONIC ANHYDRIDE SYSTEM

The carbonic anhydride system of refrigeration, sometimes called the carbon dioxide, or carbonic acid system, differsno what in the principles of operation from that of the anhydrous ammonia system. Indeed, all compression systems of refrigeration, whether anhydrous ammonia, carbonic anhydride, or sulphuric acid, are used and operated in the same way, the refrigerating agent passing successively through the stages of compression, condensation and expansion. The only difference between the three systems are found in the pressures and temperatures which in turn modify to a greater or less extent the design of the compressors and other parts.

The pressures required in the carbonic anhydride system are much higher than in the ammonia system, and the temperatures produced are lower. The carbonic anhydride systems operate under pressures of from fifty to seventy atmospheres, which would be equal to gauge pressures of from 735 pounds to 1,029 pounds per square inch, whereas ammonia systems seldom carry pressures of 200 pounds per square inch.

On the other hand, owing to the high pressure under which the carbonic anhydride system operates, its cylinders can be much smaller in diameter, consequently the entire machine can be smaller and more compact. In comparing the necessary cylinder volumes, it appears that for equal effects the following values are about right:

	Cylinder Volume
Sylphuric acid	13.78
Ammonia	5.60
Carbon anhydride	0.97

It will be seen that the compression cylinder of the carbonic anhydride machine needs to be only about one-sixth that of the ammonia machine, while the cylinder volume of the sylphuric acid machine must be more than two and one-half times the cylinder volume of the ammonia machine.

The greatest objection to the carbonic anhydride system is the great pressure it must operate under. Outside of that one objection, it is a very good system of refrigeration and can be used in places where direct ammonia or sulphuric acid systems would be objectionable. For instance, for the cooling coils of a combination heating and cooling system for a building, carbon anhydride can be used, whereas if any other system were installed brine would have to be used with the attending cost of operating a brine pump.

Among the characteristics in favor of carbonic anhydride as a refrigerating material are: Its neutrality toward water, beer, meats, victuals and other products subject to cold storage; its non-corroding

action on any of the metals; the fact that it cannot be decomposed during compression; cheapness; absence of danger to the respiratory organs in case of leaks; lack of odor and safety from explosion caused by fire.

This system can be used as a direct-acting system, or as a brine-circulating system. The direct-acting system is, of course, the less costly to install, and less expensive to operate, as is true of all refrigeration systems. Besides the cost of operating the brine pump, there is a loss of cold in transmitting from refrigerating coils to brine. The tendency of the times at present seems to be back to direct-action and away from the brine system.

CHAPTER XVI

ABSORPTION SYSTEMS OF REFRIGERATION

THE absorption system of refrigeration is dependent for its operation on the affinity of ammonia for water. Cold water, for instance, at 50° Fahrenheit and atmospheric pressure will absorb 812.8 times its own volume of ammonia gas, making what is known to commerce as aqua ammonia. Raising the temperature of the water decreases its affinity for the ammonia gas, which is driven off; while cooling the water still further increases its affinity and absorptive capacity. The foregoing explanation must be kept in mind when studying the absorption system of refrigeration, for it depends for its operation on that affinity.

The absorption of ammonia gas by water is a chemical action, and all chemical actions are accompanied by an increase or decrease in the temperature

of the mixture. This is especially true of solutions. In the case of ammonia absorbed by water, 925.7 heat units are given up for each pound of the ammonia gas absorbed under atmospheric pressure. Since heat is given up when ammonia gas is absorbed and action and reaction are equal but opposite, it follows naturally that heat will be absorbed when the gas is again liberated from the water. The quantity of heat necessary to liberate one pound of anhydrous ammonia gas is 925.7 heat units, the same amount of heat that is given out by the solution when the gas is being absorbed.

Another property of aqua ammonia to keep in mind is that the lightness or specific gravity of a solution is in proportion to its strength. Aqua ammonia of 1 per cent. strength has a specific gravity of .993 (see Table XII), while aqua ammonia of 38 per cent. strength, by weight, has a specific gravity of only .880. Owing to this fact the strongest part of a solution will always be found at the top of a tank.

Examples of Absorption Systems.—Before describing the absorption system of refrigeration, it might be well to point out its chief distinguishing feature from the compression system of refrigeration. In the compression system, the compressor is the principal part of the apparatus. In the absorption system, on the other hand, no compressor is used. Indeed, outside of a small pump, the system proper, outside of the cold water supply, has no moving parts. Chemical solutions induced by the application or abstraction of heat takes the place entirely of mechanical compression, so that the absorption system is often

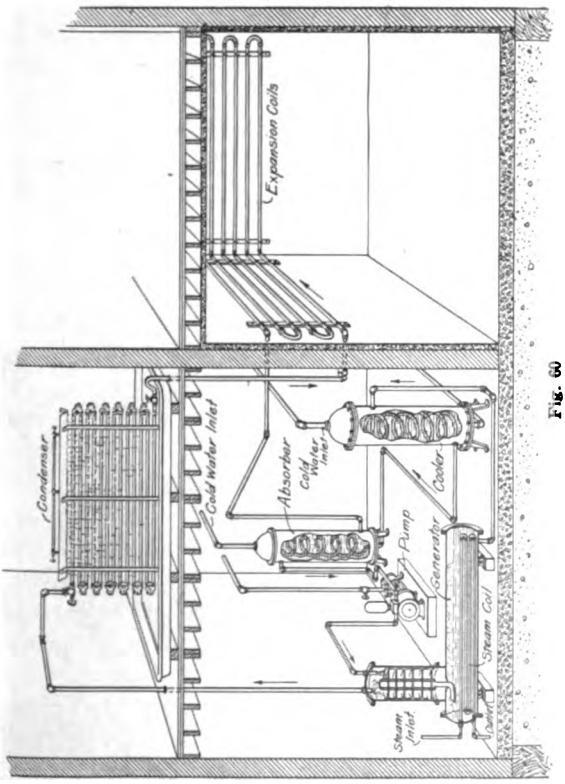


Fig. 60

Diagram of Absorption System

spoken of as a chemical system. It is well known that ammonia boils at a much lower temperature than water, so that if a strong solution of aqua ammonia be placed in a tank and heated to the comparatively high temperature of 270° F., which corresponds to a pressure of about 160 pounds to the square inch, the ammonia will be driven off from the solution in the form of anhydrous ammonia; if now cooled by passing it through a condenser it will become liquified, and in this condition can be admitted through an expansion valve to the expansion coils, located either in a refrigerating compartment or in a brine tank.

In these coils the ammonia will vaporize and withdraw heat from the surrounding objects. The vapor may now be absorbed by bringing it in contact with cold water, or with a weak aqua solution, and is then ready to begin the cycle over again.

The operation of an absorption system of refrigeration is shown diagrammatically in Fig. 60. Assume that the still or generator contains a strong solution of aqua ammonia, and the absorber a weak solution of the same. If steam is now turned into the steam coil in the generator, the ammonia will be driven off from the strong solution and will collect at high pressure and temperature in the condenser. The water flowing over the condenser coils will carry off the heat from the ammonia gas, leaving it at high pressure but low temperature, which soon liquifies it. In the liquid state it follows down to the expansion valves, where it is allowed to expand into the expansion coils, where it again vaporizes. The ammonia gas from these coils passes, following the direction of the arrow, to the absorber, where it again becomes absorbed by the

weak liquor within, thereby making a stronger solution of it. The strongest of the solution in the weak liquor tank is near the top, so the suction pipe from the pump is connected there, and discharges the strong liquor into the generator again, on a series of trays, the function of which will be explained later. The heat of the steam coils in the generator separates the solution, the strong solution rising to the top on account of its smaller specific gravity, and the fact that it wants to escape as free gas, the heating of the solution lowering its capacity to absorb gas. The weak solution falls to the bottom of the tank or generator and passes from there to the absorber, first passing through a cooling tank to rob it of its heat, so its capacity to absorb the ammonia gas will be increased.

The foregoing shows and explains the principle of operation; but in practice for economy and efficiency more parts are needed. A complete working plant, therefore, is shown in Fig. 61, and the parts will be explained in detail. The heat for the generator in this system is supplied from the exhaust from the ammonia pump; and it might be said in passing that an absorption plant can be run on either live or exhaust steam. It is heat that is wanted in the generator, and heat can be had from exhaust steam as well as from live steam. The condensers and coolers used in the absorption system are the same as those used in the compression system. It is their relation to one another, their connection, and the parts not used in the compression system which need explanation.

In the illustration will be seen an *exchanger*. This takes the place of the cooler shown in the diagrammatic illustration and has the following function:

Fig. 61

Example of Absorption System

The weak liquor from the bottom of the generator is hot and must be cooled before passing to the absorber. On the other hand, the strong liquor in the absorber is cold and ought to be heated as high as possible before being discharged into the generator. If, then, the heat in the strong liquor could be transferred to the cold but weak solution, the desired result would be obtained without the use of fuel or cooling water. This is just what is accomplished in the exchanger. The hot liquor from the generator passes through a coil on the inside of the exchanger, which is surrounded with the cool but strong liquor from the absorber, and here an exchange of heat takes place, the weak liquor becoming cooled and the strong liquor heated. The method of piping is clearly shown and needs no explanation.

As the weak liquor to the absorber might not part with sufficient heat, it is conducted from the exchanger to a double pipe weak-liquor cooler, where the temperature can be brought down to the desired degree.

A *rectifier* will also be seen in the illustration. This must be considered in connection with the analyzer, which is the upright portion of the generator. The analyzer is provided with a series of perforated baffle plates, so that the incoming strong liquor will be brought into contact with the ascending ammonia gas, or, as shown in the illustration, the ammonia gas will pass up through the analyzer in a pipe which is in contact with the incoming strong liquor. In this way the gas is cooled as much as possible, which is the object in view, and the liquor is heated in like proportion, but without the gas picking up so much

moisture as when the gas and liquid come in actual contact. No matter how much care is taken, or what form of analyzer is used, some moisture will be carried along, and it is the function of the rectifier to trap out this moisture and return it to the analyzer. The installation shown in the illustration is of the tubular type, in which double-pipe condenser and weak liquor cooler are used. Instead, however, atmospheric condensers and coolers may be used in absorption refrigeration, when it would be known as an atmospheric type; or shell condensers and coolers may be used, when the system would be known as the shell type of machine.

In the absorption system shown in the illustration the fixtures are all grouped together on one floor, thereby condensing the plant to the least possible space. This arrangement is not necessary, however, and would not be followed, for instance, where the atmospheric type is installed. Where atmospheric condensers and coolers are used, they are generally placed in a louvered shelter on the roof of the building and this necessitates the scattering of the fixtures over two or more floors. The tubular type of installation, an enclosed or pressure system, in which double-pipe or triple-pipe condensers and coolers are used; also the shell type of machine in which cylinders containing coils are used instead of tubular condensers and coolers, may be grouped in one room and confined to one floor. The type of apparatus to use in any case will generally be determined by local conditions.

When exhaust steam is used for heating the liquor in the generator, an oil separator is necessary to trap out the oil, thereby preventing it from reaching the

heating coils. This is particularly necessary when the absorption system is used for making ice by the can method, as in that case the water of condensation is used for filling the cans to freeze into ice. When live steam direct from the boiler is used for heating the liquor in the still or generator, an oil separator is not necessary, but when the system is connected up for the use of either live steam or exhaust steam, an oil separator becomes a necessity.

Whether the fixtures are grouped together on one floor or scattered throughout several rooms on different floors, all of the pipes and fixtures which contain gases or liquids above or below the ordinary temperatures of the rooms must be well covered with insulating materials to prevent loss of or absorption of heat. A refrigerating machine, it must be remembered, is a heat-exchanging apparatus, and for the best results the heat must be exchanged only at the point where the exchanges are intended to take place.

The great distinguishing feature between the compression system of refrigeration and the absorption system is, one is a *power* installation, the other is a *heat* operated apparatus. Power must be generated or be available to operate the compressor of a compression system of refrigeration, while heat in any form, will serve to operate the main apparatus of the absorption system. Exhaust steam may be used for this purpose, coal could be used, oil, wood, or any other heat producing materials. As a matter of fact, however, steam, either live or exhaust, is used for this purpose. Exhaust steam is the most economical when available. After having been used

expansively in the cylinder of an engine, exhaust steam still possesses over 900 available heat units per pound of steam.

It would naturally follow that wherever a sufficient quantity of exhaust steam can be had that otherwise would go to waste, that the absorption system of refrigeration would prove very economical to operate. On the other hand, an ammonia compressor can be operated with any kind of power, so that where power is inexpensive and exhaust steam not available, the compression system would perhaps prove the more economical.

CHAPTER XVII

DETAILS OF ABSORPTION SYSTEM

GENERATORS.—Generators and analyzers are usually combined in one, as shown in Fig. 62. These rest on the floor of the refrigeration machine room, but even then require a high ceiling room to accommodate them. Vertical generators and analyzers combined have been made, but they are not so satisfactory as horizontal generators. Owing to the small evaporating space vertical generators sometimes boil over, and the gas is always well saturated. Besides, the extreme height of vertical generators and analyzers makes them very unsatisfactory. So unsatisfactory, in fact, that they are seldom used now.

The generator and analyzer are well insulated in practice and covered with a wooden casing or shell, to prevent the loss of heat by radiation.

Steam Coils for Generators.—The size of steam coil will depend upon whether exhaust steam or live steam is to be used, the pressure of steam to be carried and the condenser pressure to be carried.

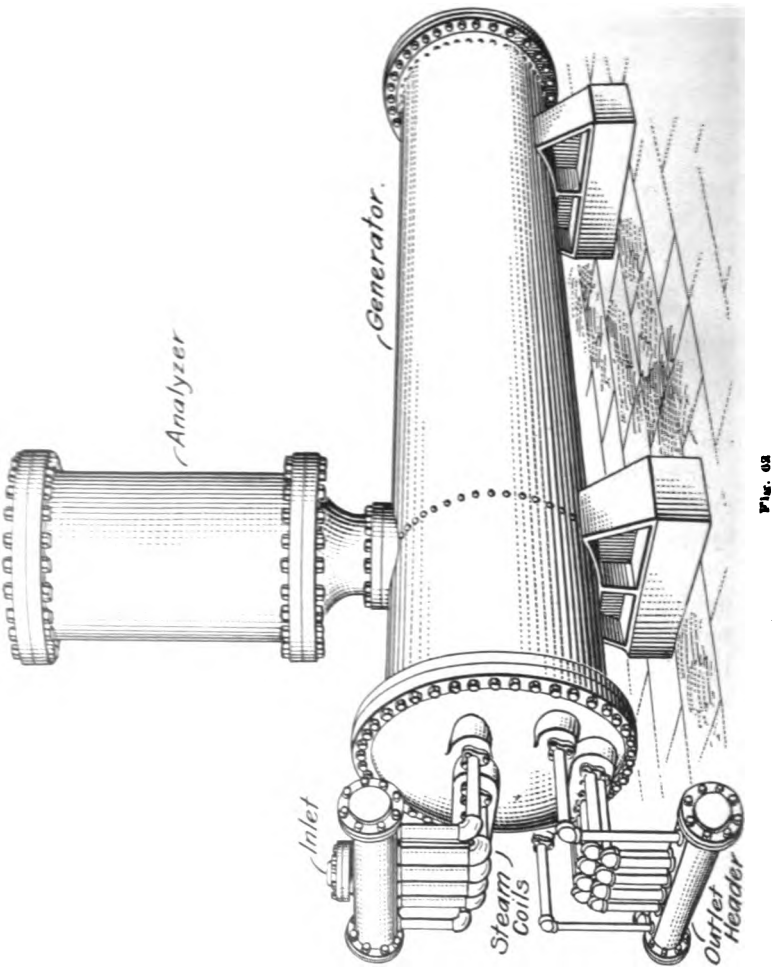


Fig. 63

When these data are known the amount of pipe required can easily be calculated, for every pound of ammonia gas liberated from the solution requires 925.7 heat units to perform the work. Owing to the corrosive action of ammonia on brass and copper, pipes of those materials cannot be used for the steam coils, which of necessity must be made from wrought pipe. Each square foot wrought pipe heating surface will transmit 200 B. T. U. per hour to the liquor for each degree difference between the temperature of the liquor and that of the steam within the coils.

Fig. 63 illustrates the wooden covering or casing that is used to protect the generator from loss of heat by radiation.

The temperature of steam at varying pressures can be found in Table XXXII.

The size of steam coil required to liberate a certain amount of ammonia from solution can be found by means of the following rule:

RULE.—Divide the total number of B. T. U. required by 200 times the difference between the temperature of the steam in the coils and the ammonia liquor in the generator. The quotient will be the number of square feet of pipe coil required.

Expressed as a formula:

$$S = \frac{H}{200\ (T-t)}$$

in which

S = square feet of wrought pipe
H = total number of heat units required
T = temperature of steam in coils
t = temperature of liquor in analyzer

TABLE XXXII

PROPERTIES OF SATURATED STEAM

Gauge Pressure per Square in Pounds	Pressure Above Vacuum per Sq. In. in Pounds	Temperature in Degrees Fahrenheit	Total Heat in Heat Units at 32° Fahr.	Heat in Liquid from 32° in Heat Units	Heat of Vaporisation or Latent Heat in Heat Units	Density or Weight of 1 Cubic Foot in Pounds	Volume of 1 Pound in Cubic Feet	Factor of Equivalent Evaporisation at 212° Fahrenheit
.....	1	101.99	1113.1	70.0	1043.0	0.00299	334.50	0.9661
.....	2	126.27	1120.5	94.4	1026.1	0.00576	173.60	.9738
.....	3	141.62	1125.1	109.8	1015.3	0.00844	118.50	.9786
.....	4	153.09	1128.6	121.4	1007.2	0.01107	90.33	.9822
.....	5	162.34	1131.5	130.7	1000.8	0.01366	73.21	.9852
.....	6	170.14	1133.8	138.6	995.2	0.01622	61.65	.9876
.....	7	176.80	1135.9	145.4	990.5	0.01874	53.39	.9897
.....	8	182.92	1137.7	151.5	986.2	0.02125	47.06	.9916
.....	9	188.33	1139.4	156.9	982.5	0.02374	42.12	.9934
.....	10	193.25	1140.9	161.9	979.0	0.02621	38.15	.9949
.0	14.7	212.00	1146.6	180.7	966.0	0.03793	26.78	1.0000
.03	15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003
5.3	20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051
10.3	25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099
15.3	30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129
20.3	35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157
25.3	40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182
30.3	45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205
35.3	50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225
40.3	55	286.89	1179.4	256.3	913.1	0.1299	7.698	1.0245

45.3	60	292.51	1171.2	261.9	909.3	0.1409	7.007	1.0263
50.3	65	297.77	1172.7	267.2	905.9	0.1519	6.583	1.0280
55.3	70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295
60.3	75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309
65.3	80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323
70.3	85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337
75.3	90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350
80.3	95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362
85.3	100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374
90.3	105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385
95.3	110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396
100.3	115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406
105.3	120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416
110.3	125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426
115.3	130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435
125.3	140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453
135.3	150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470
145.3	160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486
155.3	170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502
165.3	180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517
175.3	190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531
185.3	200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545
210.3	225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576
235.3	250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605
260.3	275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632
285.3	300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657
310.3	325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680
335.3	350	431.90	1213.7	406.9	806.8	0.728	1.337	1.0703
360.3	375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724
385.3	400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745
485.3	500	466.57	1224.2	444.3	779.9	1.065	0.939	1.0812

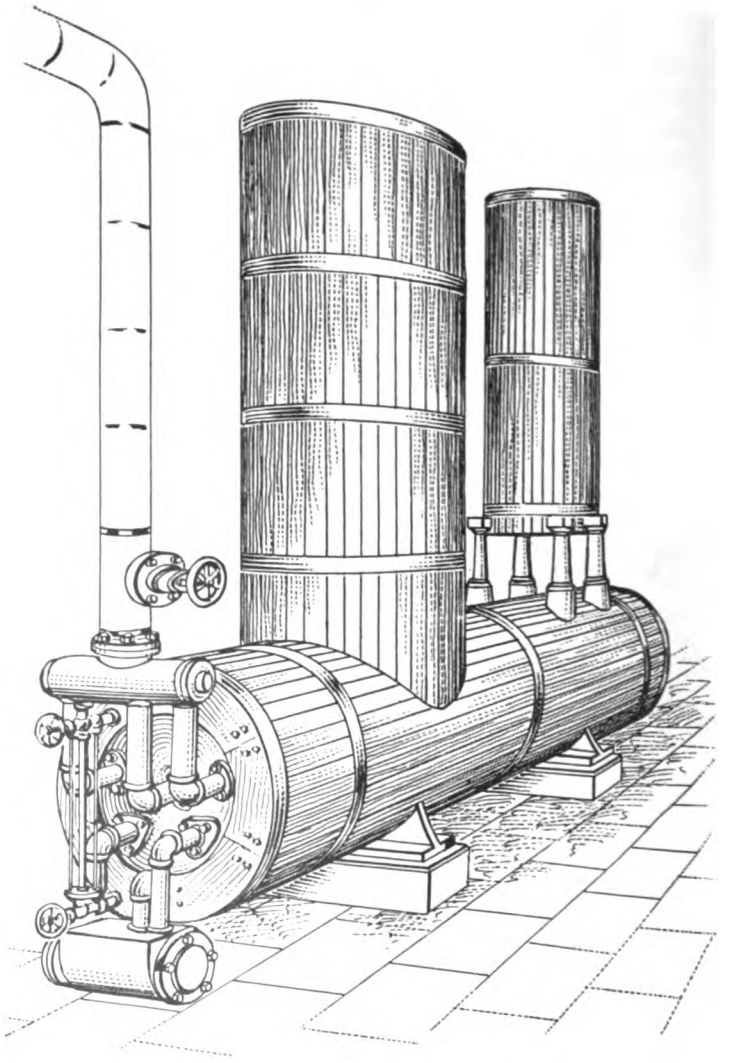


Fig. 63
Method of Insulating Generator

EXAMPLE.—How many square feet of wrought pipe surface will it require to liberate from solution 500 pounds of ammonia per hour, when the steam pressure is 100 pounds per square inch and the temperature of the liquor in the generator is 120° Fahrenheit?

SOLUTION.—It takes 925.7 heat units to liberate one pound of ammonia gas, and the temperature of steam at 100 pounds pressure is 337.81° Fahrenheit.

Substituting those values in the formula, then,

$$S = \frac{500 \times 925.7}{200\ (337.81 - 120)} = \frac{462{,}850}{45{,}562} = 10.1 \text{ sq. ft.} \quad \text{(Ans.)}$$

As the exact amount of heat required and the maximum capacity of the heating surface were assumed in the example, a greater allowance than 10.1 square feet would be required in practice, for owing to rust, incrustation and other causes, the maximum heat transmission will never be attained. Further, impurities in the solution might require the expenditure of more than 925.7 B. T. U. to liberate a pound of ammonia gas. For these reasons an extra allowance of about 25 per cent. ought to be made in the heating surface.

In speaking of heating surface, the inside area of the pipe must be understood, for it is to the inside surface that the heat of the steam is applied.

Rectifiers.—The ammonia driven off from the generator in the form of anhydrous ammonia gas, generally carries more or less moisture or vapor along,

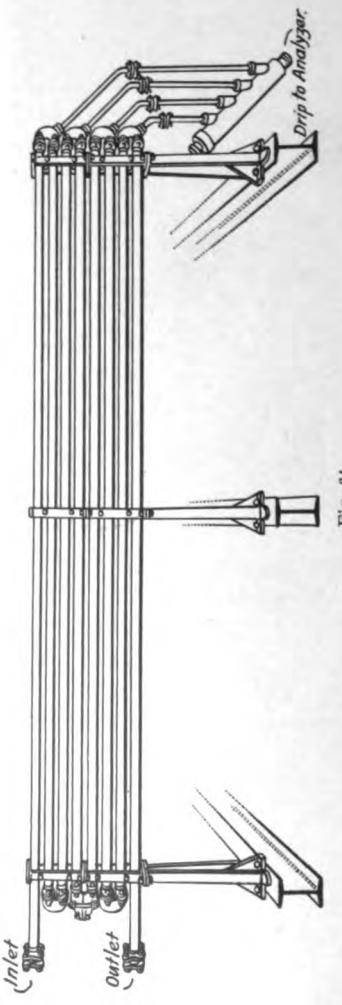


Fig. 64
Atmospheric Rectifier

which must be trapped out before the gas reaches the condenser. It is the function of the rectifier to do this. As water is heavier than gas and will always flow along the bottom of a pipe, this is an easy matter. All that is necessary is to tap or use tapped return bends on one end of the rectifier coil, and run drip or bleed pipes from these return bends to a header. This header is then connected to the analyzer, a trap being interposed to prevent gas from rising instead of the water descending.

Atmospheric Rectifiers.—An atmospheric rectifier is shown in Fig. 64. A rectifier consists simply of a coil of pipes through which the gas must travel a sufficient distance to allow the moisture to condense. There are various types of rectifiers, but they are one and all coils of pipe, and differ only in the means used for cooling the coils. In the atmospheric rectifier it may be simply exposed to the atmosphere in a cool place, where a breeze will play over it, or it may be cooled with water, as in the case of atmospheric condensers.

Tank Rectifiers.—It is plain to be seen that if the rectifier coils are submerged in running water the moisture in the gas will condense quicker, and less pipe will be necessary. This form of construction is had in the tank rectifier shown in Fig. 65. A steady stream of water can be kept flowing through this tank, and overflowing through a pipe which takes the water from the surface when it is the hottest.

Pressure Rectifiers.—A pressure rectifier, shown in Fig. 66, is in operation similar to a double pipe rectifier, in that the water used for cooling the coils

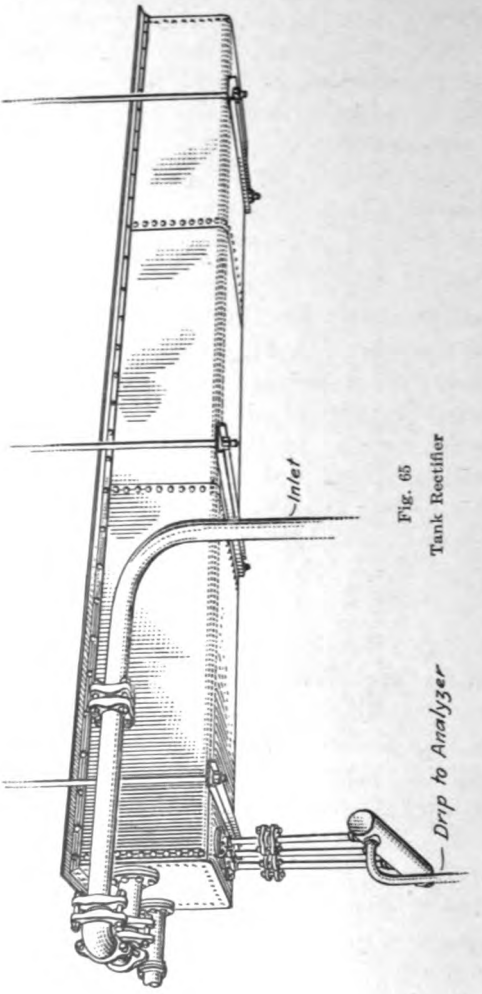


Fig. 65
Tank Rectifier

is under pressure, and can therefore be discharged at any convenient point, even though it is higher than the level of the rectifier. Water is admitted to the tank at the bottom, cools the coils in its movement towards the top, and is then discharged after having performed its work. The coils used in the three types of rectifiers illustrated are in principle the same, differing only in the modifications necessary to adapt them to the several receptacles.

Condenser Water for Absorption Systems.—The condensers used in the absorption system of refrigeration are exactly the same as those used in compression systems, but the supply of water must be greater when the absorption system is used. It will require from four to possibly five gallons of water per minute, at a temperature of 60° Fahrenheit per ton of ice, as it is necessary to keep the condensing pressure low.

Exchangers.—As was pointed out in the description of the absorption system of refrigeration, the object of the exchanger is to exchange the heat of the weak liquor passing from the generator to the absorber, for the cold of the strong liquor passing from the absorber to the generator. This is accomplished by bringing one of the liquors in contact with pipes through which the other liquor is flowing. This brings about a transfer of heat, raising the temperature of one liquor and lowering the temperature of the other, until the conditions under which they enter the exchanger are completely reversed. The liquor which enters the exchanger cool, leaves it relatively hot, while the liquor which enters it hot leaves it cool.

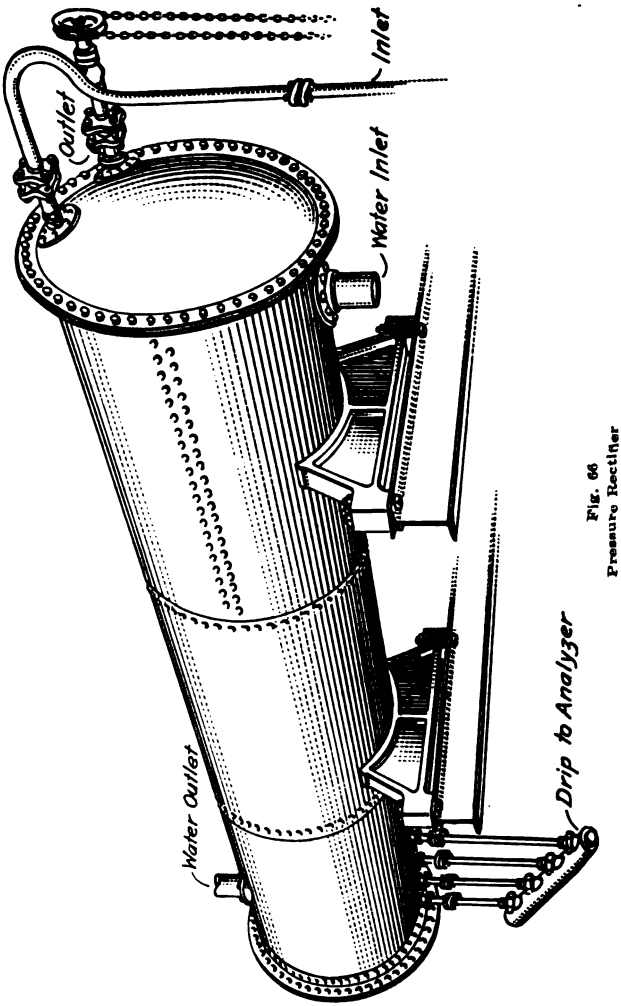


Fig. 66
Pressure Rectifier

As in all the apparatus used in refrigeration, any method which will give satisfactory results is acceptable, so the modifications are numerous in the construction of exchangers, but the one fundamental principle of bringing one liquid in contact with pipes through which the other is flowing is common to them all. So it is we find double-pipe exchangers used similar to double-pipe condensers, or double-pipe brine coolers. Also, there are the shell type of exchangers in which a pipe coil is enclosed in a cylinder, one liquor flowing through the pipe coil, the other circulating around it in the shell of the cylinder or exchanger. Usually about six square feet of pipe surface is allowed in the exchanger for every ton of refrigerating effect, and if the liquor passing to the absorber is not sufficiently cooled after passing through the exchanger, it is conducted through a weak-liquor cooler, which is simply a condenser type of coil submerged in water or having water flowing over or through it. From 3 to 10 square feet of pipe surface is allowed in this coil per ton of refrigeration effect, the amount depending on the amount of heat that must be withdrawn and the temperature of the cooling water.

Absorbers.—Absorbers are made in three types: The shell type, which is vertical; horizontal tubular pressure type, and atmospheric absorbers. The atmospheric absorbers are not much used, being at their best when the water for cooling purposes is warm. The evaporation of warm water is rapid, therefore a smaller quantity is required than for the shell or tubular types.

In the absorber the ammonia gas from the expansion coils is brought in contact with the cooled weak liquor from the generator, thereby making a hot, strong solution ready to be pumped back to the generator to begin the cycle anew. There are various ways for bringing the cold weak liquor and hot gas together. In some absorbers the hot gas and weak liquor are brought into the bottom of the absorber, so they will be in contact when their affinities for each other are at the best. In others the weak liquor is sprayed into coils along with the hot gas, which is absorbed as the two pass through the coils together. Still other absorbers are so constructed that the cool weak liquor is sprayed into the absorber, where, as a spray, it comes in contact with the hot gas. In all types of absorbers water coils are required to keep down the temperature of the solution and create a partial vacuum, or at least make the absorber the point of lowest pressure in the system, so gas from the expansion coils and weak liquor from the generator will flow there by gravity. The low pressure is helped out in the absorber by the ammonia pump, which has its suction pipe connected to the absorber and discharges into the exchanger, thereby lowering the pressure in the absorber at the very time it creates a greater pressure in the exchanger.

Ammonia Pump.—The principal thing to be considered about the ammonia pump is that it has no brass, copper or other metal parts of like nature which will be easily corroded by the liquor. The pumps are usually run at slow speed, are not subjected to severe service, and any good pump with tight

valves, which complies with these requirements, will prove suitable for the purpose.

Comparison of Absorption and Compression Systems.—There can be no doubt but that for some purposes and under some conditions one system of refrigeration will prove better than another, but as a general rule it may be said that there is no material difference in the efficiencies of the two systems, and one or the other can be adopted with equal satisfaction. For central station work the absorption system would probably prove the more satisfactory, and if plenty of exhaust steam is available, the more economical. The only power part in an absorption system is the ammonia pump, the exhaust from which can be utilized, while in the compression system a large compressor is required. More water is required, on the other hand, for the absorption system than for the compression system, so that matters tend again to equalize each other. The fairest opinion that can be given, perhaps, is that either system will give perfect satisfaction. Whether one system will prove better than the other will depend a good deal on whether there is going to waste where the plant is to be installed an abundance of exhaust steam which can be utilized in an absorption system, thereby cutting down the cost of coal to that required for pumping water for cooling purposes. Where water power is available the compression system can be economically operated, as the water power can be utilized for this purpose.

The absorption system uses anhydrous ammonia only as a refrigerant. This is because no other

known substance lends itself so readily for the purpose. Water has an affinity for, and will absorb large quantities of many gases, but of none of them will it absorb so large a quantity as of ammonia. For instance, at atmospheric pressure and ordinary temperature, pure water will absorb 4 per cent. of its own volume of air; 4 per cent. of its volume of sulphureted hydrogen; 100 per cent. of its volume of carbon dioxide, and about 800 per cent. of its volume of ammonia.

COLD-AIR CIRCULATING SYSTEMS

THE cold-air circulating system is an indirect system of refrigeration, because the air is cooled in a separate chamber by direct-expansion or brine coils, then forced through air ducts by means of fans, into the rooms, to be cooled. The velocity of the air does not exceed 30 feet per second, so that a gentle circulation is maintained in the rooms, which is well adapted to the preserving of some products. The rooms refrigerated by this system are free from dampness and foul odors, but the shrinkage, of the stored goods is liable to be greater than with a direct system of refrigeration, because the air in passing over the coils deposits its moisture in the form of frost or ice, and its affinity for moisture becoming increased as its temperature is raised in the storage rooms, the air will absorb moisture from the stored food products. An arrangement is made to change the air whenever necessary by forcing it out-of-doors, and drawing a fresh supply from without. A heat ex-

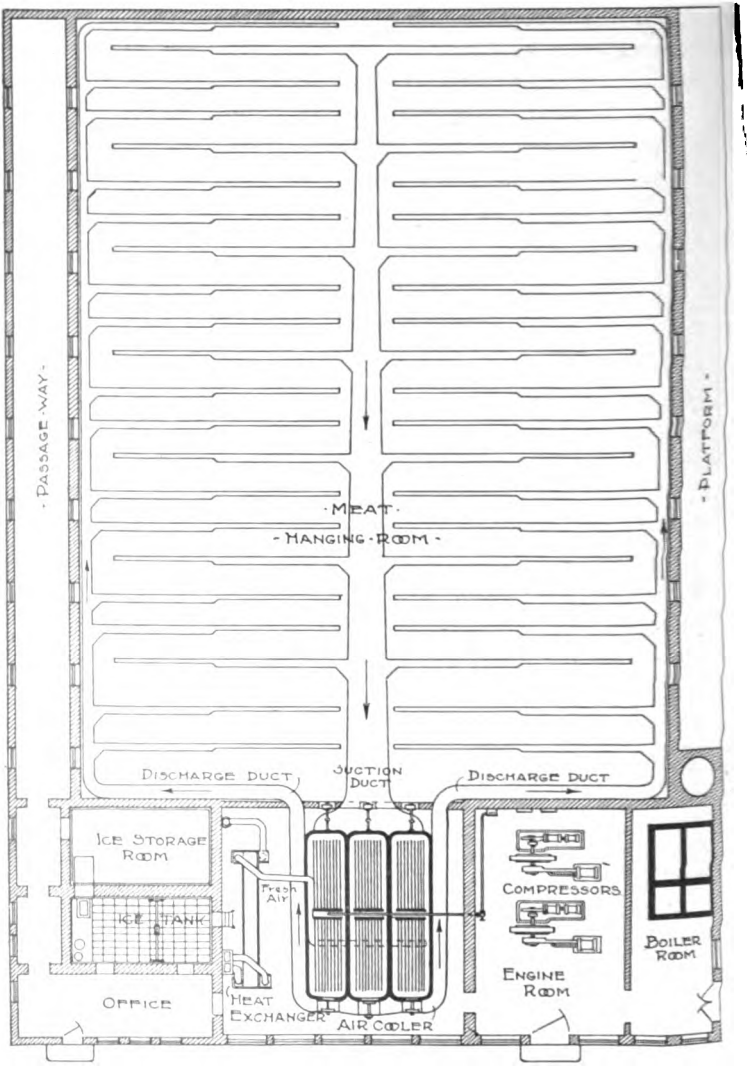


Fig. 67
Cold-Air Circulating System

changer is employed for this purpose, so that the incoming pure air can be cooled by the outgoing spent air.

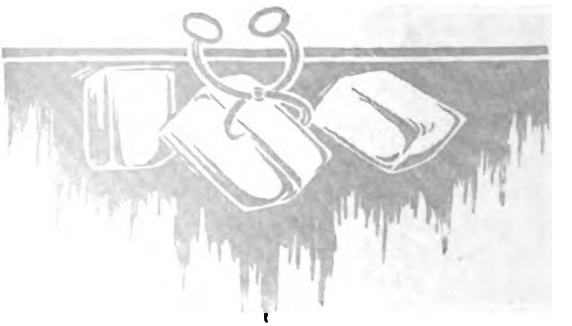
The general arrangement of a cold-air circulating plant is shown in plan in Fig. 67. In this system a carbonic anhydride refrigerating machine is used, so the air coolers are composed of a series of direct-expansion pipes, calculated for a certain amount of work, and so arranged that the connections are made outside of the coolers. Brine coils would be preferable to direct-expansion ammonia for a cold-air circulating system, for a slight leak in an ammonia coil would taint the air, and the air coming into intimate contact with the stored food stuffs would spoil them.

Large fans take care of the circulation of cold air, forcing it through the two main inlet ducts running along the two sides of the room, while the suction duct located in the center of the room carries back the air to the coils to be re-cooled. As was pointed out above, the air becoming relatively warmer in circulating, has its capacity to absorb moisture increased, and draws for its supply upon the stored food. In passing over the expansion coils the air becomes chilled again, its capacity to hold moisture thereby becomes decreased, and the excess moisture will be deposited on the direct expansion pipes and must be thawed off from time to time.

An indirect system of refrigeration modified somewhat from that shown in the illustration, can be, and has been used with good effect in cooling public places of assemblage, such as court rooms, theatres, halls and restaurants, during extremely

hot weather. Usually refrigeration coils are provided in connection with the heater coils of the combined heating and ventilating system, so that when the refrigerating material is turned into the cooling coils and the fan started, cold air, instead of hot air is forced into the rooms to be cooled.

The cooling of public places during the summer months, hotels, theatres, restaurants, office buildings, schools, workshops, etc., has not been so extensively used in the past as it might have been. There is a great and growing field there which will be developed in the future, with benefit and profit to those who are enterprising enough to adopt the idea. There is no reason why direct system of cooling could not be used as well as indirect systems, and, why simple apparatus would not adapt it to present house heating apparatus, utilizing the pipes and radiators already installed.



CHAPTER XIX

APPLICATION OF REFRIGERATION

RESIDENCE Systems and Other Small Plants.—Mechanical refrigeration is so much more sanitary than refrigeration with natural ice, that refrigeration systems are pretty generally installed at the present time in large residences, apartment houses, hotels, institutions, and stores where perishable goods are handled and sold. The general use and distribution of electric current makes the operation of small systems safe and convenient as well as inexpensive. Mechanical refrigeration has likewise supplanted natural ice in most industries, and is found almost indispensable in breweries, distilleries, abattoirs, packing houses, market houses, butcher shops, fish curing establishments, fish markets, dairies, creameries, milk depots, confectionery and ice cream manufacturies, oil refineries, chemical works, morgues, bottlers, hotels, restaurants, club houses, asylums, steamships, general cold storage houses and for cooling water in office buildings and other large structures. Refrigeration is made use of also for congealing soft earth and quicksand for excavating purposes.

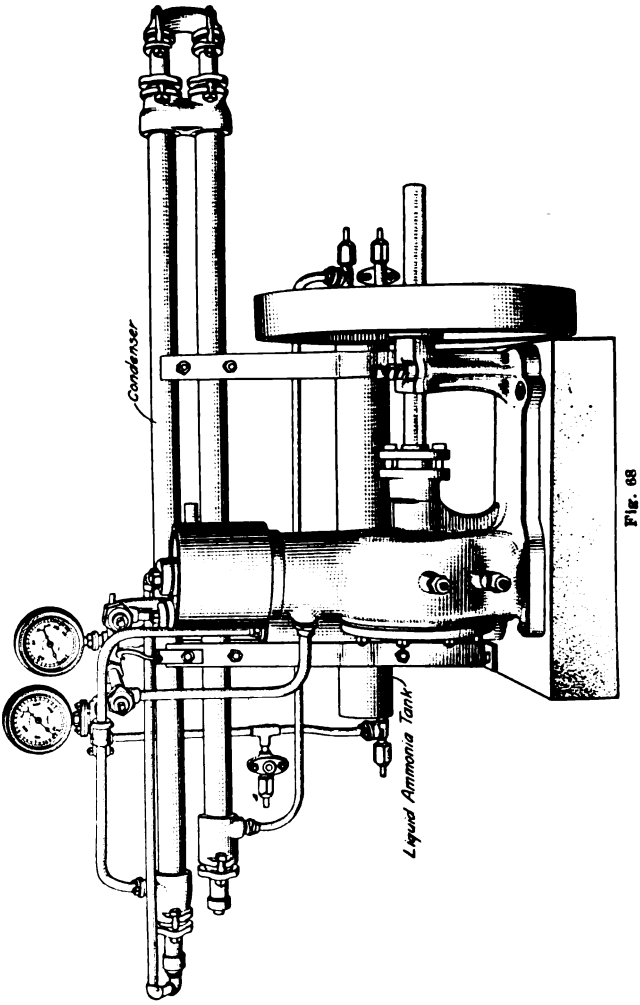


Fig. 68
Small Refrigerating Machine

Portable refrigerating machines of small capacity mounted on a solid base so the entire plant can be easily transported from place to place are now made. In Fig. 68 is shown a machine of this description made by the Remington Machine Company. It is made in two sizes, having capacities respectively of one-quarter ton per twenty-four hours and one-half ton per twenty-four hours.

These machines are especially suited for the cooling of refrigerators or small cold-storage rooms of from 200 to 1,000 cubic feet capacity, depending on the temperature required. The machine is erected on one base with condenser and fixtures connected together, all properly valved, so all that is required is the pipe coil for the cooling of the refrigerator or storage room. It will be noticed that the compressor is belt driven, and the machine requires from one to two horse-power for its operation, depending upon the size of the machine.

PORTABLE ICE MAKING AND REFRIGERATING MACHINES

Small Refrigerating Systems—A portable ice-making machine is shown in Fig. 69. This machine is made in two sizes. One has a capacity of 250 to 300 pounds of ice in twenty-four hours, or 100 to 150 pounds in twelve hours. The other has a capacity of 500 to 600 pounds of ice in twenty-four hours, or 250 to 300 pounds of ice in twelve hours. The small machine occupies a floor space 8 by 4 feet, is 4 feet high, has a driving pulley 24 by 3 inches, and is designed to be run at a speed of 200 revolutions per minute. It has a shipping weight of 1,850 pounds,

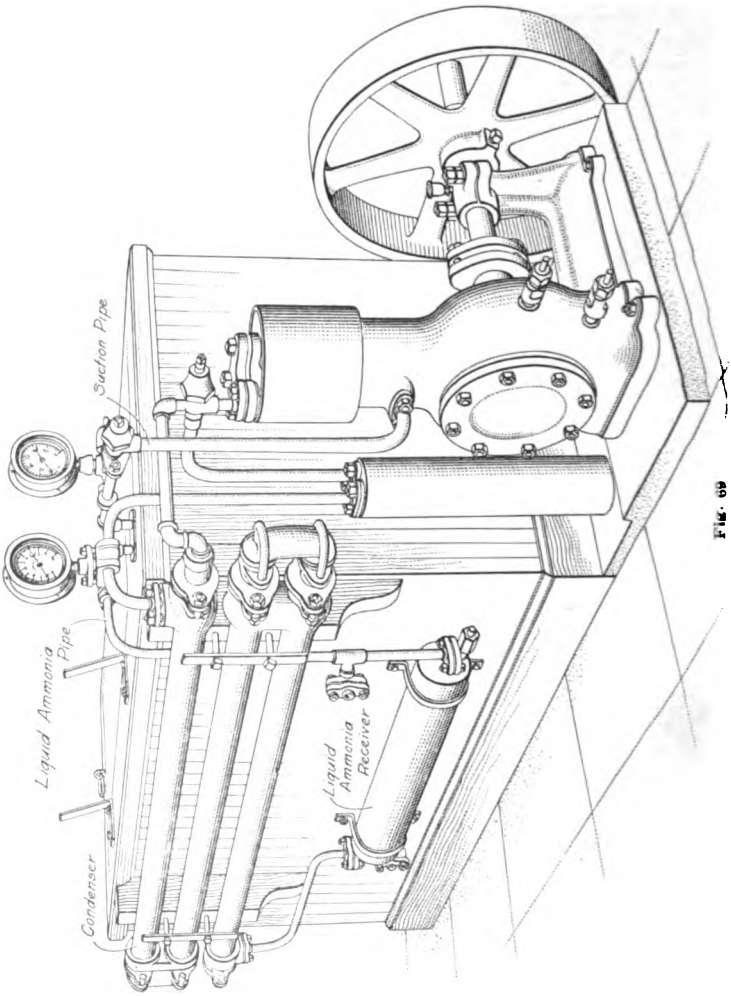


Fig. 69
Small Refrigerating and Ice Making Machine

and requires one horse-power to operate it. The large machine requires a floor space 9 by 4 feet, and is 4½ feet in height. It has a driving pulley 24 by 4 inches, speed 200 revolutions per minute, requires two horse-power to operate it and has a shipping weight of 2,500 pounds. The outfit consists of an ammonia compressor, condenser, freezing box provided with expansion coils, ice cans holding from 10 to 12 pounds each in the smaller size, and 22 to 24 pounds each in the larger size. The ice box and machine are mounted on one base and connected together with valves and fixtures, making a complete portable ice-making outfit, ready to be connected to a belt for operation. It is crated and shipped in this condition. The freezing box has a small cold-storage compartment under a separate cover for the preservation of a small amount of provisions.

In starting the machine it is necessary only to connect the belt, fill the freezing compartment with a strong solution of calcium or salt brine, and connect a water supply of about one or one and a half gallons of water per minute to the ammonia condenser. About eight hours are required to cool the brine and walls of the ice box to the freezing temperature, after which the plant is ready for the making of ice.

In Fig. 70 is shown a portable combined ice-making and refrigerating machine of the Remington type. These machines have the combined capacities of the two machines just described.

Water-Cooling Refrigerating Machines.—Mechanical refrigeration is now generally used for

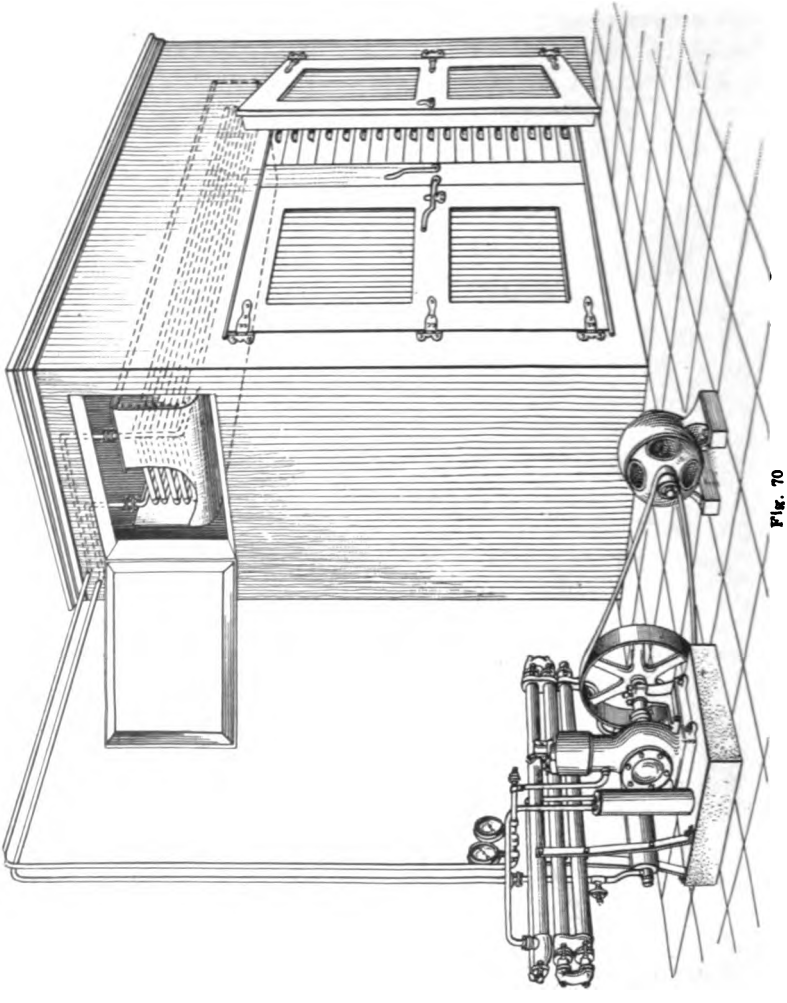


Fig. 70
Small Refrigerating System for Store

cooling the drinking water for large office buildings, hotels, clubs and like buildings. This requires a miniature plant of its own, or an expansion or brine coil from the general system, when refrigeration for other purposes is required in the building.

The complete refrigerating system for a water-cooling plant is shown in Fig. 71. This was designed with a capacity of from twenty-five to thirty drinking fountains, and is operated by an electric motor. In supplying ice water to a building a pump is necessary to keep up a circulation through the supply pipes, so that cold water will be on tap the moment a faucet is opened. If the water were not kept in circulation, it would soon grow warm, and considerable water would have to be drawn before cold water could be obtained. From the circulating pump the risers are taken to the attic, or 10 or 12 feet above the level of the highest fixture, if there are none on the top floor, then returned and discharged into the cooling tank. In some cases a small tank called a "balancing tank" is provided in the attic, and the water from the risers discharge into this, the overflow being carried back to the cooling tank in the cellar or basement. Supply branches to the drinking fountains are taken off the up-risers, so there will always, be a supply available, and under a suitable head or pressure.

It is very necessary to insulate thoroughly the ice-water pipes or they will condense the moisture in the atmosphere, thereby "sweating" and being a nuisance generally.

Layout of a Small Refrigeration System.—In Fig. 72 is shown the layout and piping for a com-

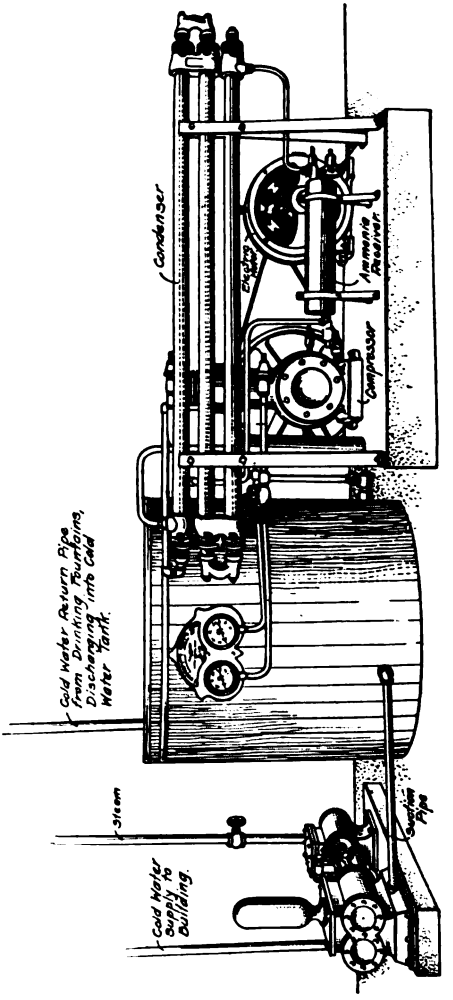


Fig. 71
Mechanical Water Cooling Apparatus

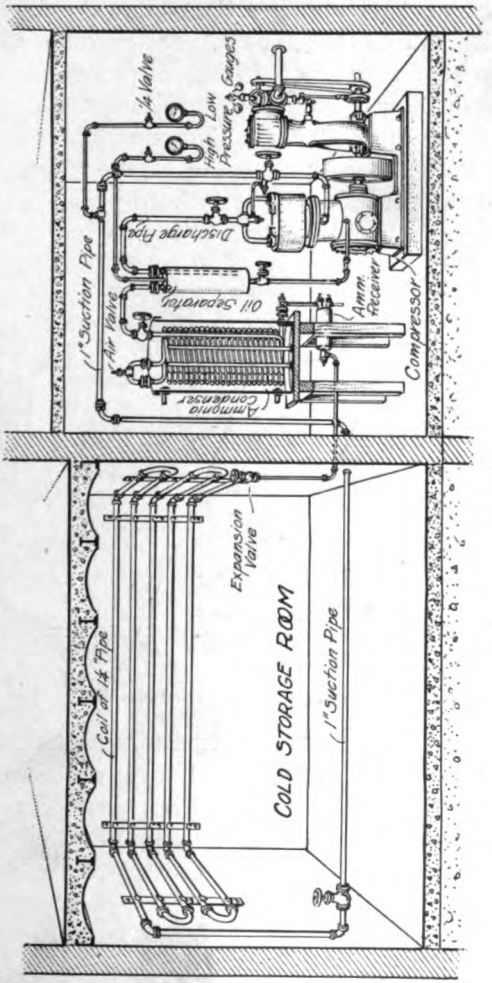


Fig. 72
Small Direct-Expansion Systems

Fig. 71
Mechanical Water Cooling Apparatus

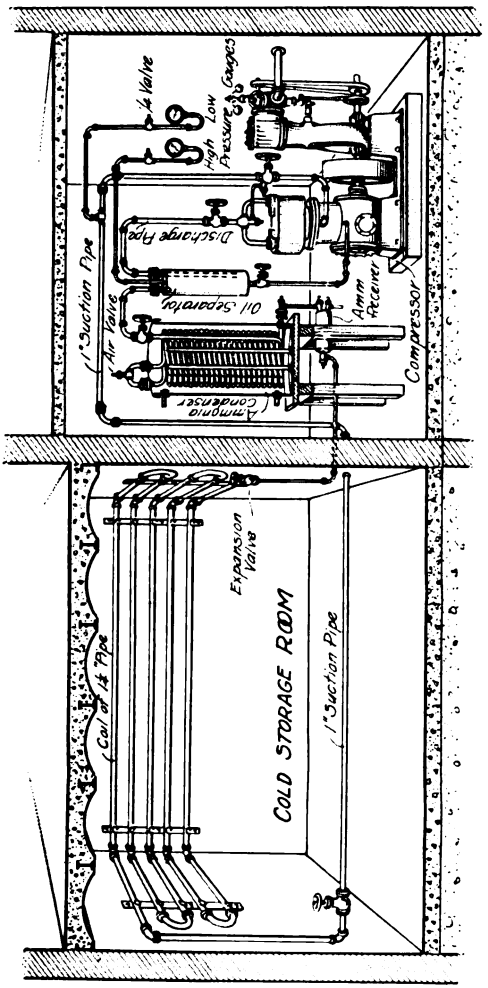


Fig. 72
Small Direct-Expansion Systems

plete small refrigeration plant of the direct ammonia-expansion type. Instead of the engine shown in the illustration, an electric motor, belt, gasoline engine, gas engine, or any other prime or secondary mover may be employed to drive the compressor. The layout of the apparatus can likewise be arranged to suit the floor space, for outside of the sequence of the various operations there is hardly any limit to the arrangement and location of the parts.

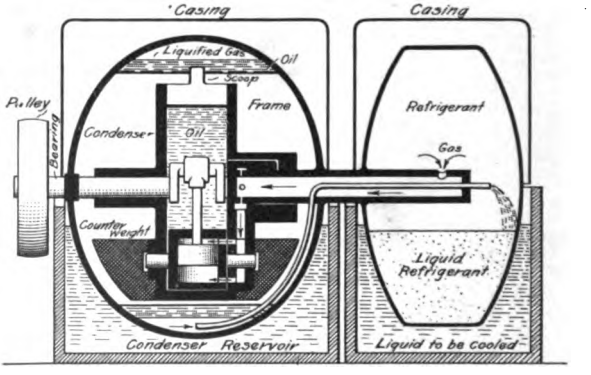


Fig. 73
Audiffren-Singrun Refrigerating Machine

Audiffren-Singrun Refrigerating Machine.—The simplest refrigerating machine yet designed, and the one which brings mechanical refrigeration nearest to the home, is the Audiffren-Singrun machine shown in Fig. 73. This little apparatus, designed for homes, apartments, clubs, stores and like places, where ice making capacities of from 11 to 110 pounds an hour is all that is needed, are as nearly fool proof as it is possible to make anything of this nature.

The operator does not need to understand the machine or its operation any more than he does an electric-lighting system. All that is necessary is to throw on the electric current when the machine is to be operated, and cut off the current to throw the machine out of operation.

This machine uses sulphur dioxide hermetically sealed inside of the machine, as a refrigerating medium. The liquid cannot leak away, and therefore never has to be renewed. The air is exhausted from the machine at the factory, and the right charge of refrigerant placed within so that thereafter, until the machine gets out of order, it will keep up the refrigerating of the compartments it is intended to cool, or freeze water into ice, when operated.

The compressor, which is simplicity itself, is hung from the shaft with loose hangers, and counterweighted at the bottom to keep it in an upright position, and act as a safety device by preventing the pressure rise above that determined by the designer. Lubrication is affected by a forced flow of oil to prevent metal-to-metal contacts, and reduce wear to the lowest possible limit.

The sizes, capacities, power, speed and other details of the Audiffren-Singrun refrigerating machines can be found in Table XXXIII:

It is not necessary to operate these machines all the time. For ordinary service it will be necessary to run the machine only for a certain time during the morning, and again in the afternoon to maintain the temperature required. The temperature is maintained during the interval by the action of the cold brine, which was cooled during the time the machine

was running. This gradually absorbs the heat which flows into the refrigerator through the insulation.

Any form of power is suitable for operating the Audiffren-Singrun Machine. Generally speaking, the electric motor is the most practical and convenient means of supplying power and is usually preferred where it is available. The machine can, however, be operated equally well by a gas or gasoline motor, by a steam engine, or by a water-wheel or turbine where a fall of water is available.

TABLE XXXIII

CAPACITIES OF AUDIFFREN-SINGRUN MACHINES

No. of Machine	Cooling Effect (equiv. of Ice melted) lbs. per hour	Ice Making Capacity, lbs. per hour	Cond'ns Water Required at 70° F gallons per hr.	Cond'ns. Water Required using Ecn'mzr gallons per hr.	Power Required H. P.	Speed, Rev. per min.
2	16	11	26	1	.4—.6	380
3	40	27	95	2	1—1¼	280
4	80	55	190	3	2—2¼	190
6	160	110	380	5	4	140

Where electric current for power is obtainable at 6 cents per K. W. hour, and condensing water at $1.00 per 1,000 cubic feet, these machines will furnish refrigeration at from 16 cents to 22 cents per hundred pounds.

A small system of refrigeration with brine tanks is shown in Fig. 74. In this system brine is used, but without brine circulation. The object is to store up enough cold within the compartment to be cooled so the compressor can be shut down over night and the storage rooms still remain cold, and be that way in the morning. This is accomplished by locating

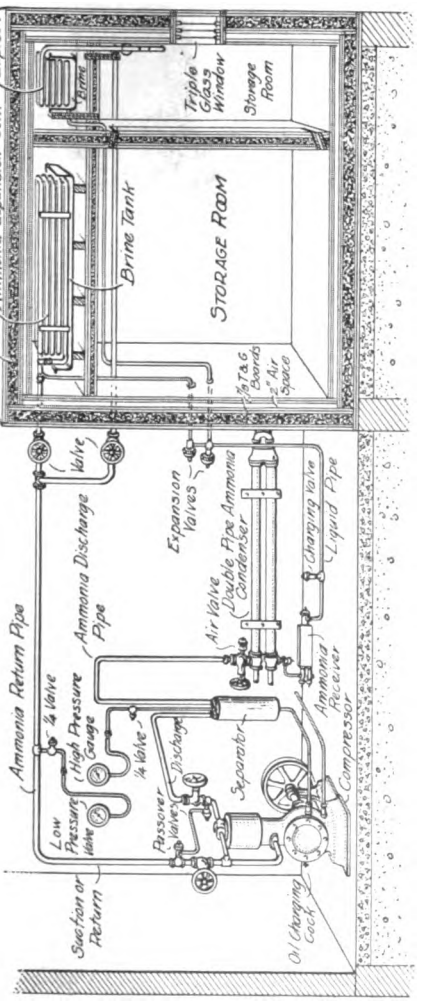


Fig. 74
Small Brine System of Refrigeration

a brine storage tank overhead, as shown in the illustration, with space for the air to circulate from the compartment underneath up around the brine tank and back to the cold storage compartment again.

A brine pump is not necessary for such a system, and at the same time the brine in the tank will part with its cold, or what amounts to the same thing, absorb heat from the storage rooms during the time the plant is shut down.

MECHANICAL REFRIGERATION IN BREWERIES

Making of Beer.—To thoroughly understand the application of refrigeration to brewery work necessitates a general knowledge of the making of beer. Grain, generally barley, is moistened and heated artificially to cause the grains to sprout, in which condition the starch becomes more soluble and suitable for fermentation. The sprouting grain is then kiln dried after the growing has been carried far enough, thereby checking all further growth of the plants. This process is called *malting* and the malted grain is called *malt.*

The next stage is to boil the malt with hops in large brewing kettles. The liquid drawn off from the kettles is known as *wort* and is what later becomes beer. After leaving the brewing vats the wort is cooled, in mechanical refrigeration, a Boudelot cooler being used for the purpose. When cooled, the wort is stored in large fermenting vats, or tanks, where yeast is added to seed with the right kind of ferment. It is a peculiarity of beer yeast that it is at its best only when subjected to certain temperatures,

ranging according to the kind of yeast and other local conditions between 40° Fahrenheit and 60° Fahrenheit. If the temperature should fall and remain below that minimum, or rise and remain above the maximum, the wort would be liable to become seeded with wild yeasts, or other ferments, which would affect the quality of the product materially, if indeed it did not spoil it altogether. It is necessary, therefore, to keep the wort in the fermenting vats at a uniform and suitable temperature.

The vaults or cellars where the fermenting vats are located are kept cool by means of refrigerating coils, but the process of fermentation develops heat in the wort itself, and this heat must be removed as soon as generated. The heat of fermentation is taken care of by means of attemperators, or cooling coils, placed within the fermenting vats.

After fermentation the beer is drawn off into tuns or vats in the storage cellar, where it is allowed to settle and age. The cooling cellar is kept at a temperature of from 34° to 38° Fahrenheit. From here the beer is drawn off, kegged or bottled, and is then ready for sale.

In brewery refrigeration practice a complete system of mechanical refrigeration is required, which may be a compression system, ammonia or carbonic anhydride, or an absorption system. Also, it may be a direct expansion system, a brine system, or any combination or modification of direct expansion and brine systems that may seem advisable. As the general principles of refrigeration have already been explained, it will be necessary here to describe only those special parts or apparatus used in brewery refrigeration.

Boudelot Coolers.—A Boudelot cooler which is cooled by direct expansion of ammonia is shown in Fig. 75. The wort passes from the brewing kettles to a large, shallow tank, open to the atmosphere, where it is allowed to cool from its original temperature, about 200° Fahrenheit, to a temperature of about 110° Fahrenheit. It is then allowed to trickle down over the Boudelot cooler, thereby being reduced in temperature to about 40° or 45° Fahrenheit. It will be observed that the cooler is made in two sections. The upper part is made of copper pipe, tinned or polished on the outside, and through this section ordinary cooling water flows, passing in at the bottom of the coil and out at the top, so that the warmest water will be in contact with the pipes, where the hottest wort is flowing over, and all of the excess heat of the water passes to the wort near the bottom of this section, where the water is the coolest. By this means the wort is cooled to a temperature of about 60° Fahrenheit, before reaching the ammonia expansion coils of the cooler. The ammonia expansion coils of the cooler are made of polished steel pipe and polished steel ammonia fittings, on account of the corrosion which would be affected by the ammonia should the coils be made of brass or copper. With direct expansion, the temperature of the wort can easily be brought down to 40° Fahrenheit.

A Boudelot cooler for beer wort in which brine is used instead of direct expansion ammonia, can be seen in Fig. 76. Instead of using brine, however, pure cold water can be and often is used in the lower pipe sections of the cooler as a refrigerating medium. If ice cold water is used in the lower pipe sections of

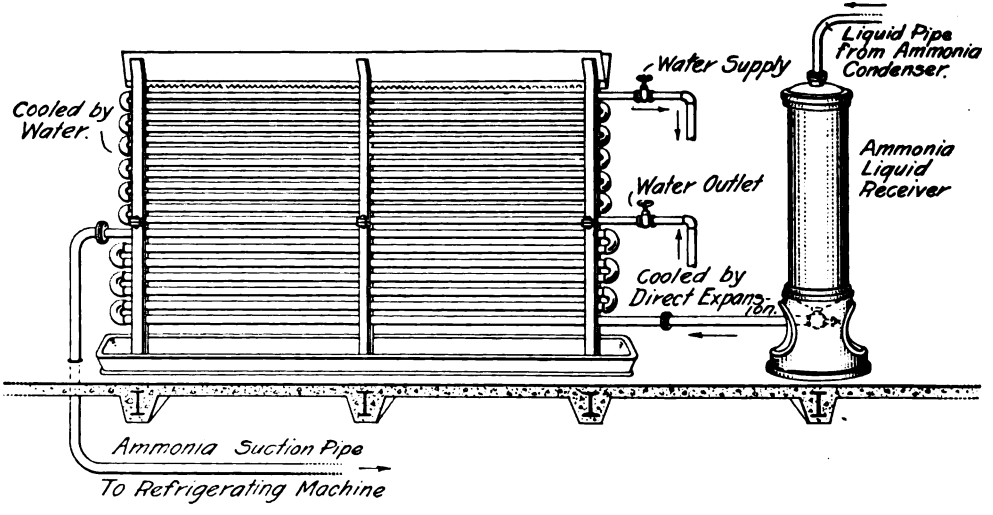


Fig. 75
Boudelot Cooler, Direct Expansion

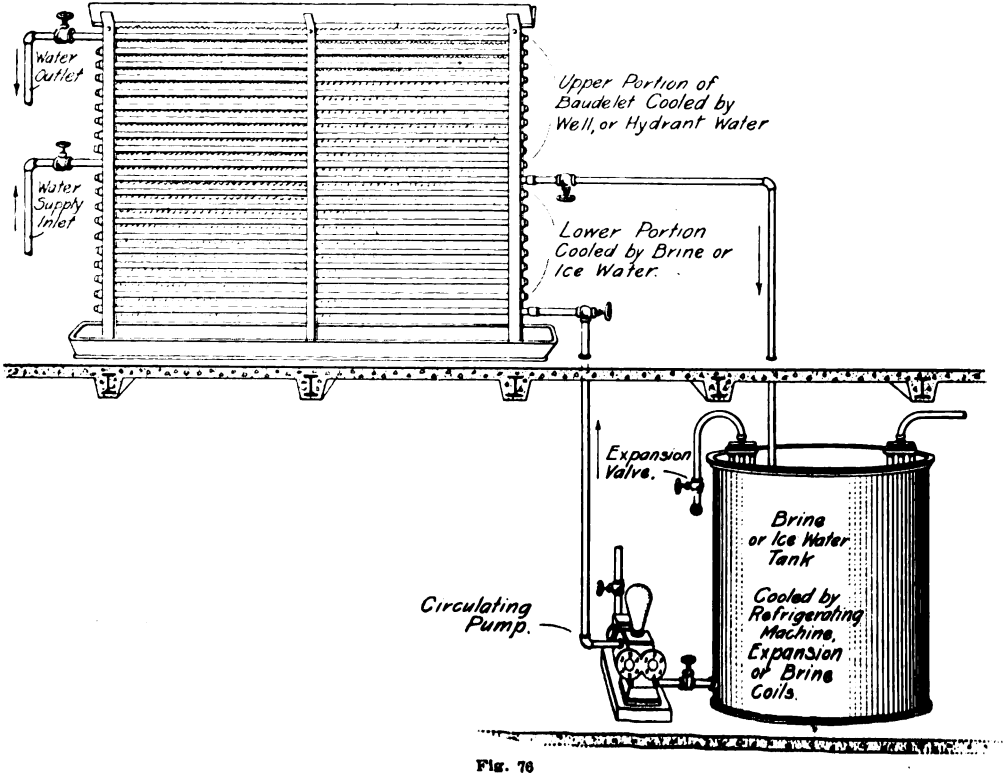

Water Outlet
Water Supply Inlet
Upper Portion of Baudelet Cooled by Well, or Hydrant Water
Lower Portion Cooled by Brine or Ice Water.
Expansion Valve.
Brine or Ice Water Tank
Cooled by Refrigerating Machine, Expansion or Brine Coils.
Circulating Pump.

Fig. 76

the cooler, ordinary polished or tinned copper pipe fittings may be used, and copper pipe, polished or tinned, instead of the steel pipe and ammonia fittings required when direct expansion ammonia is used. Otherwise the construction of the cooler does not differ, and in operation it differs nowhat from the cooler previously described.

Milk Coolers.—For cooling milk, apparatus similar in design to the Boudelot beer cooler is used. This is accepted as being the most practical way of cooling beverages, where it is desired to reduce the temperature rapidly without danger of freezing.

Attemperators.—An attemperator system for regulating the temperature of fermentation is shown in Fig. 77. As a minute leak of either brine or ammonia would taint the contents of the fermenting vats, the cooling medium used in the attemperators is generally pure water, commonly called "sweet water," cooled by brine. The water is circulated through the attemperators by means of a pump, and the attemperators are located at the top of the tubs, where they will do the most good. The hottest liquid in the tubs will naturally be at the surface, and if this heat is constantly withdrawn, it will be as constantly supplied from the liquid lowered down in the tanks, so that a fairly uniform temperature of the right degree will be maintained. The attemperator coils are kept clear of the sides of the tubs, so there will be a free circulation around them and so the pipes can be easily cleaned. Usually, enough pipe surface is provided to allow about 12 square feet of cooling surface for every 100 barrels capacity of the tanks or tubs.

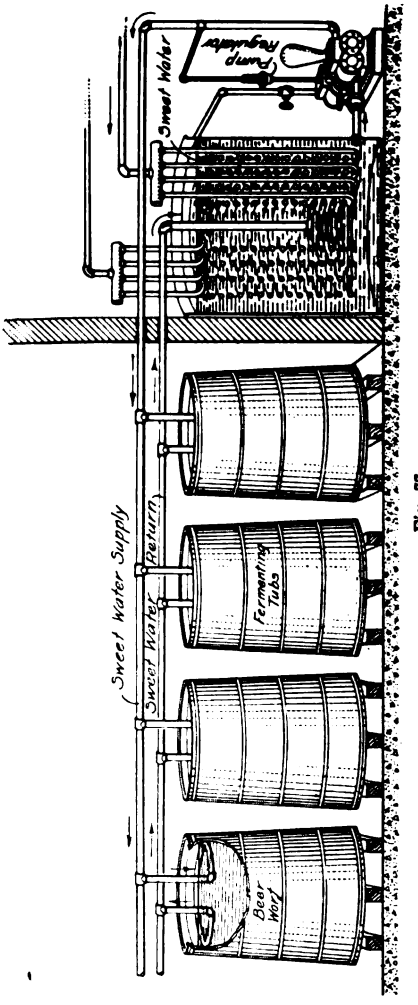


Fig. 77
Attemperators for Fermenting Tubs

Cooling Coils for Fermenting Room.—The refrigerating coils in fermenting rooms are variously arranged to suit the requirements in each case, care being taken to avoid drips from the pipes into the tubs. One method of arranging the pipe coils is shown in Fig. 78. There is less danger of water drip-

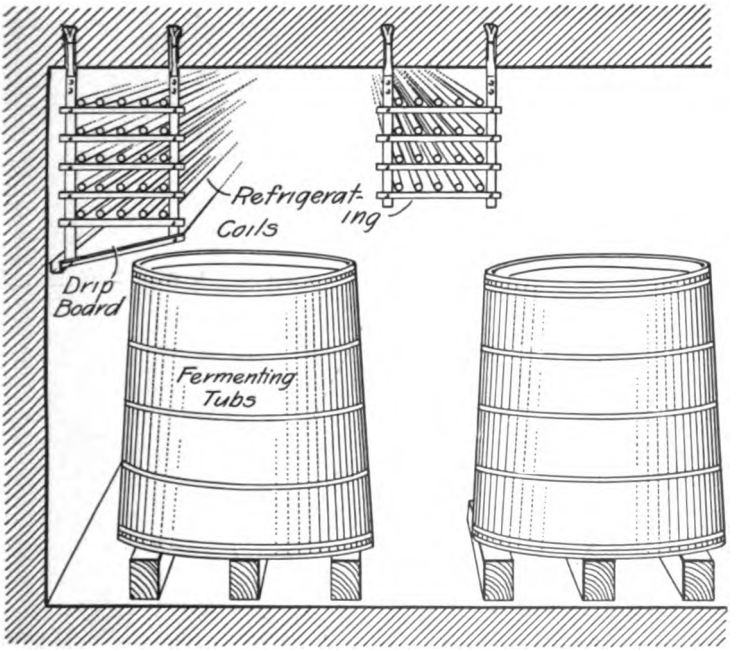


Fig. 78—Cooling Coils in Fermenting Room

ping into the vats when the brine is shut off with this system of piping than when the pipes are spaced grid-like on the ceiling. It is well to keep the pipe coils high instead of low, because a better and more uniform temperature can be maintained in that manner.

Cooling Coils for Storage Vaults.—After the process of fermentation has been completed, and the wort has been converted into beer, it is drawn off

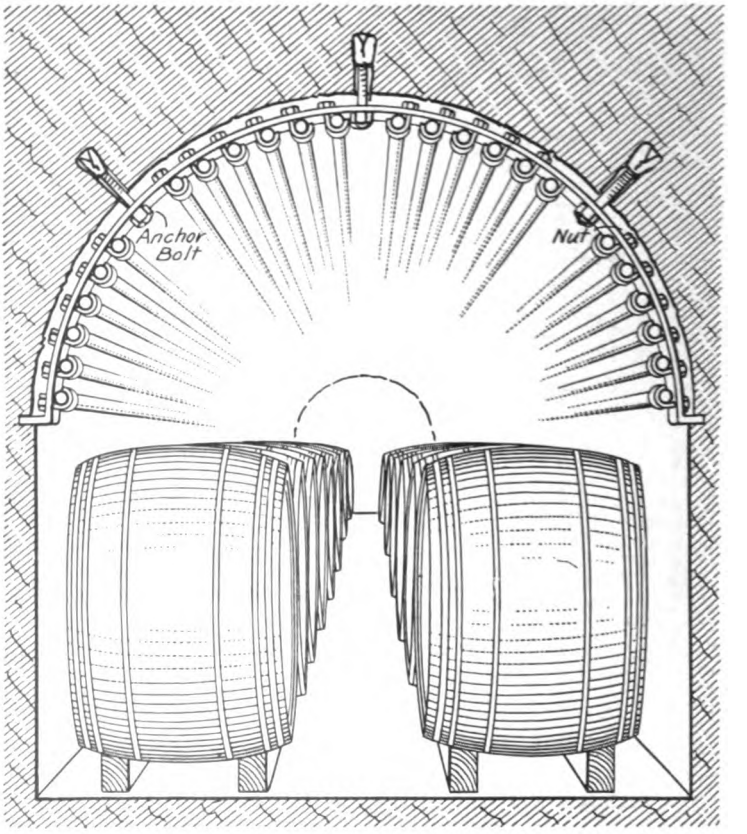


Fig. 79
Cooling Coils in Storage Vaults

from the fermenting tubs into casks or tuns in storage vaults, where it can settle and age. These vaults

are cooled either by means of brine coils or direct expansion coils, and, as the beer, when placed in storage, is well reduced in temperature, only enough cooling surface need be provided to maintain the contents of the vault at a temperature of from 34° to 38° Fahr. The coils for this purpose are generally placed overhead. In Fig. 79 is shown one method of arranging the pipes on the arched surface of the vault ceiling. It will be noticed that each hook supporting a pipe is attached to the main support by means of a nut, so that any one line of pipe can be removed and replaced without disturbing the other lines of pipe.

The amount of refrigeration required for storage vaults had better be calculated in each case by means of formulas already given. The amount will vary

TABLE XXXIV

SPECIFIC HEAT OF WORT

Strength of Wort According to the Balling Saccharimeter at 60° Fahrenheit	Specific Gravity of the Wort a 60° Fahrenheit	Specific Heat of Wort at 60° Fahrenheit
8	1.0320	.944
9	1.0363	.937
10	1.0404	.930
11	1.0446	.923
12	1.0488	.916
13	1.0530	.909
14	1.0572	.902
15	1.0614	.895
16	1.0657	.888
17	1.0700	.881
18	1.0744	.874
19	1.0788	.867
20	1.0832	.861

from one ton of refrigeration for 7,000 cubic feet of space, to one ton of refrigeration for 14,000 cubic feet

of space, according to the exposure of the vaults, their size, ordinary temperature, temperature of the beer when stored, and kind of insulation used.

In calculating the amount of refrigeration required for brewery work, the specific heat of wort of different strengths must be known. This information can be found in Table XXXIV:

Refrigeration for Packing Houses.—In packing house and abattoir practice, refrigeration has but three applications outside of the usual refrigeration processes already described. That is a chilling room is required in which the pork, beeves and mutton are placed after slaughter, in order to cool them from slightly below blood heat, 95° Fahrenheit, to a proper storage temperature, which is about 35° Fahrenheit. The slaughtered animals are left to cool a few degrees in a well-ventilated room before taking them to the chilling room. The chilling rooms for their purpose are kept at a temperature of about 28° Fahrenheit.

From the chilling room the carcases are taken to a storage room maintained at a temperature of about 35° Fahrenheit, where they are kept until wanted.

Besides the chilling room and storage room, special freezing rooms of a temperature of 10° above zero, Fahrenheit, or under, are necessary, as it is often desirable to freeze the meat before shipping.

Coils for Chilling Rooms.—Brine circulation, as a rule, is preferable to direct-expansion ammonia in the chilling rooms, and where head room is not restricted, the system of piping shown in Fig. 80 will be found the most suitable for the purpose. Where

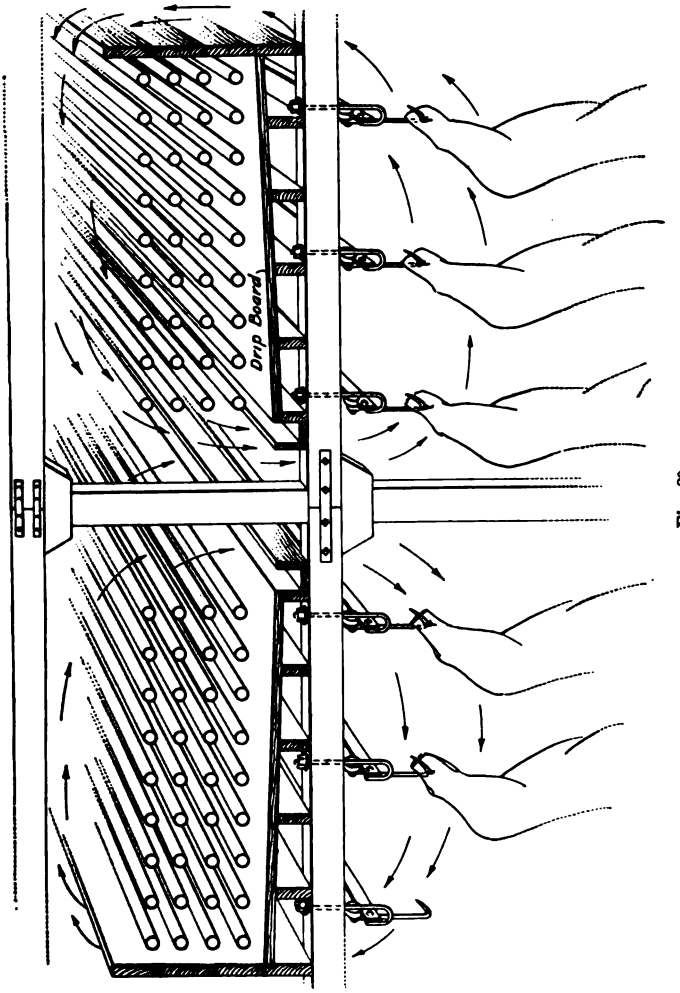


Fig. 80
Coils for Chilling Room

head room is lacking, the coils may be placed on ceiling and side walls, the same as in storage vaults of breweries.

With coils such as are shown in the illustration, there is a circulation from the carcases where it is heated and moistened, to the pipe coils, where the air is again cooled and deprived of its moisture, which settles on the coils in the form of ice. This is rather favorable to the meat, as it withdraws at the same time both the animal heat and the excess moisture.

The coils are usually made of $1\frac{1}{4}$-inch pipe and are made up in lengths of from 300 to 600 feet, with valves on the inlet and outlet, so the temperature may be regulated by cutting out or throwing into service, as occasion requires, one or more coils. A gutter is provided at the side of the drip board to carry off the water when the ice is cut or thawed from the coils. The drip boards are preferably lined with some metal to keep the moisture from dripping through onto the meat stored beneath.

While brine circulation is preferable to direct ammonia expansion on account of less danger of spoiling the stored goods in case of a leak, that is the only advantage in favor of brine, so, as would be expected, direct expansion is also used for this purpose.

When direct-expansion coils, or brine coils with brine at 0° or cooler are used, 1 square foot of pipe surface will be found sufficient for from 20 to 21 cubic feet of storage space. In the case of brine circulation at 15° above zero, 1 square foot of pipe surface will be sufficient for only $11\frac{1}{2}$ to $12\frac{1}{2}$ cubic feet of storage space. It takes 2.3 lineal feet of $1\frac{1}{4}$-inch pipe to equal 1 square foot of outside pipe surface.

The other rooms in packing houses differ from the chilling room principally in the temperatures required. Any method of piping heretofore explained, or any modifications of the systems may be used, and the amount of refrigeration may be determined by the rules and formulas already given.

EXCAVATING BY THE FREEZING PROCESS

Quicksand and Swampy Soils.—In building operations it is often necessary to sink shafts or make other excavations in soft, watery soils; in order to get a solid footing for the foundations of pillars and walls of buildings. In some cases the soil is soft from the surface down, as, for instance, in the salt Jersey marshes. At other times, a stratum of quicksand will be found intercalated between two beds or strata of dry and solid material, which have to be pierced in sinking the shaft down to the required level.

The soil of swamps and salt marshes is usually of a heavy nature, consisting of vegetable materials, decomposed and black with age and change. In some places the interlacing roots of growing vegetation give a greater or less stability to the mucky soil, but, as a rule, it is very unstable and hard to excavate for the reason that, being over-saturated with water, it flows, if not exactly like water, at least like a more sluggish and viscous fluid. By confining the space to be excavated with sheet piling, and keeping the enclosure free from water by pumping, the excavation can be successfully prosecuted, as it likewise can by means of the freezing process.

Quicksand, on the other hand, is of mineral origin. It is nothing more or less than sand, usually very fine, generally with rounded forms, which move freely over one another, and sometimes united with a small percentage of very fine clay or possibly some loam. It owes its peculiar characteristics to the fact that it is highly saturated with water—so highly saturated, in fact, that the grains are buoyed up and the slightest pressure displaces them. When not completely covered with water slight tramping will bring the water to the surface, and when subjected to any disturbance it will quake like jelly. In this condition it is not only troublesome, but dangerous.

If, after having become quaky, quicksand is left quiet and undisturbed for a few hours, the heavier particles settle to the bottom, expelling the water, so that the mass becomes reasonably firm again. If, on the other hand, when in the quaky condition it becomes still further disturbed, it will take up more water and become more and more fluid, until it becomes almost as unreliable as water for supporting any weight, and more difficult to manage.

Quicksand is perhaps the worst material with which the builder has to deal. Excavations made in this material are always troublesome, and often attended with great danger. To attempt to make an excavation in quicksand which is thoroughly saturated with water, by any of the ordinary methods, is like attempting to drill a hole in a body of water; the hole will fill up as fast as the material is taken out, and an unfortunate misstep into a bed of quicksand is liable to engulf the workman unless assistance is at hand.

It is impossible to excavate in wet quicksand without taking means to prevent it running into the excavation space from the sides and bottom, and one of the best means to this end is the freezing process of excavating.

Poelsch Freezing Process.—There have been a number of methods suggested for freezing soft fluid earth in excavating, all of them similar in general principles of operation, but differing slightly in detail and in the refrigerating agent used. The Poelsch process, however, is the only one used to any extent in practice, and the one commonly accepted as the standard.

The method of using the Poelsch freezing process, and the apparatus used, outside of the refrigerating plant, is shown in perspective in Fig. 81. Freezing pipes are driven down through the soft material to be excavated and into a solid stratum beneath. These freezing pipes are then connected above ground by means of a main header, and a branch from the main header leads to the suction pipe of a pump so that the liquid used for freezing purposes can complete its cycle by being pumped back into the brine tank. The circulating pipes which are inside of the freezing pipes are likewise connected above ground, and the main brine pipe from the header is connected to the brine tank. The short connections between the header and the freezing pipe, also between the header and the circulating pipes, are controlled by valves so that any one line can be cut out of service for repairs. All pipes above ground, and where heat is not to be withdrawn, must be protected

Fig. 81
Method of Freezing Ground for Excavating

with a good covering of some non-heat-conducting material, so there will be no waste of power and the cold will be applied where most needed.

The freezing pipes in the illustration are shown driven in a perpendicular position. Sometimes, however, they are driven with an outward pitch toward the bottom, particularly in deep excavations, so that the ice wall will be thicker near the bottom where the greatest pressure will have to be borne. Driving the freezing pipes down into a solid stratum below the quicksand insures the bottom level of the soft material being congealed so that it can not flow through at this point and fill the shaft.

Cold brine is used as the freezing medium in this process of freezing earth for excavating, and a complete refrigerating apparatus, of course, is necessary for cooling the brine. A portable outfit for this purpose can be had; and the compression system in which anhydrous liquid ammonia is the refrigerant is the type of apparatus commonly used.

The use of galvanized pipe and fittings is best for the purpose. Rust scales on black iron pipe have been known to lodge in one or more of the circulating pipes, thereby blocking them and rendering them useless. This is liable to produce a weak spot in the ice wall, if not discovered in time, for with any of the freezing pipes out of use the ice around them is liable to thaw.

Installing the Freezing Pipes.—The most costly and difficult part of the installation is putting the freezing pipes in place. In soft earth free from big stones or other obstructions, the freezing pipes

can be driven. Where the quicksand is between two strata of solid earth, however, particularly when some distance from the surface, the holes are better drilled to the required depth, and the freezing pipes placed in the holes so drilled. If no boulders are encountered the drilling is a simple process, which becomes complicated and costly in proportion to the number of obstacles encountered. When the pipes are to be driven into place instead of making ready for them by drilling, a casing large enough for the freezing pipe to slip inside of is first driven down to the required depth. The material is then removed from inside of this casing, the freezing pipe lowered into place, and the casing is then withdrawn, leaving the freezing pipe in contact with the earth, which closes in about it.

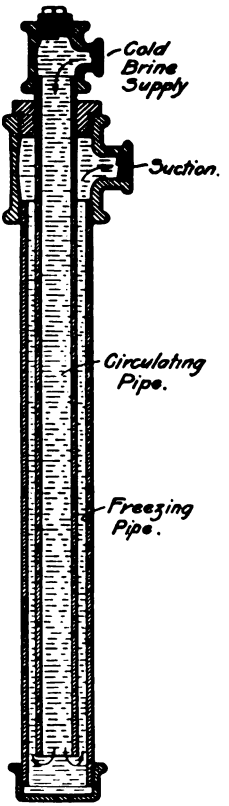


Fig. 82
Refrigerating Pipe for Freezing Soft Earth

Detail of Circulating and Freezing Pipes.—The combination of circulating pipe and freezing pipe is shown in Fig. 82. The outside pipe, which is in contact with the earth, is known as the freezing pipe, while the inner tube is known as the circulating pipe. In this form of apparatus the cold brine moves in the small

tube in the center of the freezing pipe, and from there escapes at the bottom into the freezing pipe, where it rises and overflows into the suction pipe. It will be observed that when this order is followed the coldest of the incoming brine is in contact with the pipe surrounded by the heated outgoing brine, and is consequently robbed of part of its cold before it has had time to perform the work for which it is being circulated. It will be found better in practise, therefore, to reverse the order shown in the illustration, and discharge the cold brine direct into the freezing pipe, using the circulating pipe for suction. Either method may be used, however, at the option of the engineer in charge.

It is necessary that the freezing pipe be absolutely tight. Should a leak permit the brine to escape and saturate the ground around the freezing pipes, it would become more difficult to freeze the earth, if indeed not impossible, for salt water outside of the freezing pipes will not freeze any more readily than when inside of the pipes. A few large leaks, moreover, would entirely defeat the object of a freezing plant and process.

In shallow workings the circulation pipe is supported by the fittings, as shown in the drawing. In deep shafts, on the other hand, the circulation pipe is allowed to rest on the cap at the bottom of the freezing pipe, and slots are cut around the pipe at the lower end to allow the fluid to flow from one pipe to the other.

Insulation of Freezing Pipes.—In shaft-sinking where the freezing pipe for any reason has to pass

through a stratum of earth which does not need to be held in place by freezing, the pipe can be insulated at such points so there will be no transfer of heat, and no unnecessary consumption of power. By the simple process of insulation, a transfer of heat can be made to take place at any point or points along the line while at other points the freezing process is entirely suspended.

Expansion Joints or Fittings.—Allowance must be made in deep workings for expansion and contraction. As the pipe cools it contracts in length, diameter, and area, and the cooler the pipe becomes the more it contracts. When first installed the pipe is of its maximum size, and is of the temperature of the earth surrounding it. When chilled brine is allowed to flow inside, the pipe chills somewhat, but there is such an active transfer of heat taking place that the temperature does not drop much. Sometimes one stratum will require less heat loss to freeze it, and it will then grip the pipe like a vise, while another stratum at a different point does likewise. Any further contraction in length then puts a strain on the pipe and fittings which might cause a leak. To avoid this, in very deep shafts, it is well to provide a slip joint or expansion joint to take up the contraction of the line.

Size of Circulation and Freezing Pipes.—The freezing pipe used in this process may be of any size, and in practise it varies from 4 inches to 8 inches in diameter. The larger the pipe, of course, the greater the cooling surface, so that for quick freezing, or

where hard freezing is required, the largest size of pipe would prove the most satisfactory. Also, where there would be a great heat loss, the large sizes of pipe will be found advantageous. The size of circulating pipe ranges from 1 inch to 2 inches in diameter. It may be assumed as good practise to use 1-inch circulating pipe for 4-inch freezing pipe; 1½-inch circulating pipe for 4½ and 5-inch freezing pipe; 1½-inch circulating pipe for 6 and 7-inch freezing pipe; and 2-inch circulating pipe for 8-inch freezing pipe.

Freezing Solution.—The freezing solution used in the freezing process is calcium chloride, which must be reduced in temperature to 20° or 25° below zero, Centigrade, which is equivalent to from 4° to 13° below zero, Fahrenheit. This will require about a 24 per cent. solution of calcium chloride, or about 250 to 275 pounds of chloride of calcium to each 1,000 gallons of water used.

Process of Congelation.—When the refrigerating system is put in operation the process of congelation takes place in two distinct stages. In the first stage a cylinder of ice forms around each of the freezing pipes, and these cylinders increase uniformly in all directions until the adjacent cylinders touch when the ice unites, forming a closed wall of frozen material. In the second stage, after the ice is formed, each cylinder of ice tends to increase in a circle as before, but as the cylinders interfere with one another, a fluted annular ring is formed. After the ring is formed there is an unequal heat loss between the

inside and the outside of the wall of ice. That portion of the earth enclosed by the freezing pipes becomes successively colder, while outside of the ice wall the earth remains at its normal temperature, supplying heat continuously in an effort to melt the ice. The result is that the rings of ice increase much more rapidly inside of the ring of pipes than outside of the ring, on account of the unequal heat loss.

Time Required for Freezing.—The time required for freezing naturally varies in every case, and depends upon the nature of the material to be frozen, the thickness of the wall of ice, temperature of the material to be frozen, and of the atmosphere at the site. A semisolid material, of course, would require less time and less energy to freeze than a more fluid material in which a constant movement of water in circulation kept supplying heat almost as fast as it was withdrawn. The fluidity of a material, likewise, would determine the thickness of wall that would be required, for a heavier and thicker wall would be required to hold back a fluid material like muck or quicksand than a more solid earth.

In actual practise, taking the data from twenty-one freezings, the minimum initial freezing was 15 days, the maximum 365 days, or one year, and the average 94 days, or slightly over three months. The initial freezing period covers the time from starting the refrigerating machine to the beginning of the excavation. The freezing process is not discontinued when the excavating is commenced, but is continued in operation until the work is completed.

Strength of Frozen Materials.—The strength of the frozen material varies greatly with the nature of the material and the quantity of water present. Unless there is sufficient ground water to surround the grains of material and completely enclose them, the walls will be comparatively weak, but at the same time there will be less liability of the material flowing or caving when not frozen. When the water fills the voids between the grains of material it acts as a cement, and when frozen holds them bound together in one complete mass.

From tests made it may be stated that the tensile strength of frozen earth is 431 pounds per square inch, and the compression strength 575 pounds per square inch. As it is the compression strength which is brought into play generally, making due allowance for different materials, it might be well, perhaps, to assume an ultimate compression strength of not over 500 pounds per square inch, and freeze the wall of corresponding thickness, allowing a suitable factor of safety, to hold back the thrust of earth and water bearing against the wall.

Excavating Frozen Material.—Experience has proven the fact that it is desirable to commence excavating while there is yet an uncongealed space in the center of the shaft or working, as the excavating is thereby made easier. In such cases, however, care must be taken that the annular ice ring or wall is carried well below the level of the water-bearing material, or else the lower end of the cylinder or shaft to be excavated must be frozen solid, otherwise the fluid material will flow into the shaft when it is

carried below the frost line. When the lower end of the shaft or working is to be frozen solid it can be accomplished by insulating the central portions of the tubes where cold is not wanted. Excavating is seldom started until the ice wall is thick enough to encroach on the area to be excavated, consequently the thickness of the ice wall is rarely less than 3 feet. It was believed at one time that the ice wall around a circular shaft took the form of a truncated cone, with its greatest diameter at the base. Experience has since shown that the frozen mass may assume any shape, and does, according to the nature and specific heat of the material frozen. Some take the form of a truncated cone with the largest diameter at the base, others take the same form but with the largest diameter at the top. Some are cylinder-shaped, some a cylinder of varying diameters, and some the shape of a barrel.

The frozen material is generally about as hard and difficult to excavate as soft sandstone. In the early days of the process the frozen material was excavated entirely by means of picks, wedges, and chisels. At the present time, however, powder, dynamite, and gelatin are used for this purpose, care being taken not to use a charge large enough to shatter the ice wall or break the freezing pipes. There is less danger of damage to the ice wall, it would seem judging from past experience, than there is of breaking some of the freezing pipes.

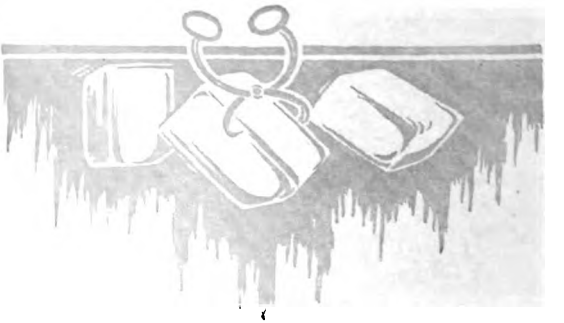
In drilling the frozen material brine will be found the best fluid to use in the drill holes. Ordinary water will freeze and hold the drill fast in place, while strong brine will have no such effect.

Lining Shafts.—When excavating by the freezing process the walls must be lined as the shaft goes down to keep the material in place and prevent an accident in case the wall gives way or thaws out. In permanent open shafts, that portion of the wall which is composed of quicksand or soft earth must be lined with a permanent waterproof lining strong enough to hold back the thrust of the soft material. In temporary excavations, on the other hand, the walls of the shaft may be lined with sheet-piling of wood or steel, whichever is the most convenient; and the sheet piling may be removed when the work is completed. Often an engineer has the footing for the foundation of a pier to start on a solid stratum below a layer of quicksand, and the freezing process can be used to good advantage for this purpose.

It must be understood, however, that the freezing process of excavating is not offered as a general method of excavating in soft or fluid earth, or wherever quicksand is encountered. Often the ordinary method of sheet piling around the excavation with interlocking sheet piling made practically watertight, and the seepage water kept out by means of pumps, will be found not only more satisfactory, but will be a quicker process than freezing a wall around the shaft to be excavated. Judgment must be exercised in selecting the method of excavating in soft earth, the same as it must be exercised in any and all other engineering problems. There is no one process which is best under any and all conditions, and the best for any one set of conditions is a matter for the engineer in charge to decide from all data at hand. In an extremely warm tropical climate it would, of course, not only

take longer to freeze a wall of ice around a shaft, than it would in a cooler climate, but it will require more power, likewise, to keep the wall of ice from thawing.

A wall of ice around a shaft or excavation is of course a sheet-piling of ice, but it is a protection for the excavation and the workmen engaged therein only so long as the wall is kept frozen. In deep workings, therefore, safety requires the additional protection of a temporary lining, in case the ice wall should thaw sufficiently to allow the soft earth to cave in.



PART X

ICE MAKING

CHAPTER XX

PLATE-ICE PLANTS

METHODS of Making Ice.—There are two principal systems for making ice, known respectively as the *plate system* and the *can system* These two systems however, have certain modifications, such as the *block system* and the *cell system* but they are only modifications, not really different methods.

Ice making, whether plate, can, block or cell method, is but one of the many applications of mechanical refrigeration. It is simply utilizing the cold produced by compression or absorption for freezing water into ice, instead of cooling a storage space, chilling beef, cooling beer, or any of the other uses to which it is put. It would follow naturally that a system of refrigeration such as was described in the preceding

chapters would be the first and most important element in ice making. But that part of the system need not be considered here. All that will be necessary will be to explain how the expansion of ammonia or the circulation of cold brine can be used in practice to freeze water, thereby forming ice.

Two important facts to bear in mind in the study or practice of ice making is that no water exists in nature absolutely pure, and that water in freezing purifies itself of mechanical impurities, or matter in suspension. Indeed, to a certain extent, freezing water will free itself of matter held in solution, and of bacteria. The more contaminated a water is with suspended impurities, however, the more power required to freeze it, for energy is consumed in forcing the suspended matter out of the freezing water. From an economic standpoint, therefore, it is better to use only filtered water in ice making. From a sanitary standpoint, no water should be used for this purpose which is not clear and wholesome.

Example of Plate Ice-Making.—In Fig. 83 is conveniently shown how plate ice is made. A large tank which may be made of any suitable material, but preferably wood, is divided up into compartments, as shown to the extreme right of the illustration. In each of these compartments is then placed one or two hollow steel or cast-iron plates, in the hollows of which the refrigerating fluid can circulate. The tanks are filled with water, and when the ammonia or brine is turned into the hollow between the plates, it begins to absorb heat from the water in the tank. When the temperature of the water has been sufficiently

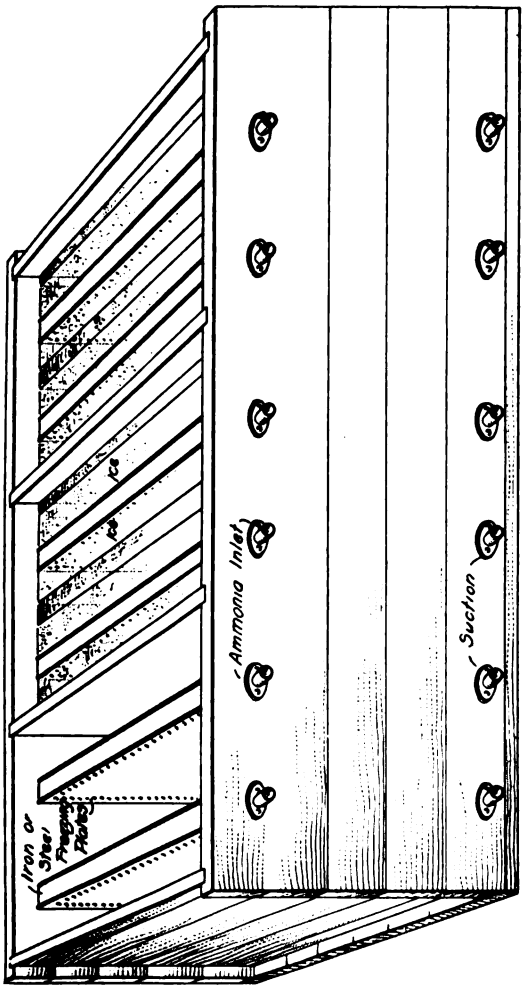


Fig. 88
Tank for Making Plate Ice

lowered, ice begins to form in thin layers all over the surface of the hollow plates, and this layer keeps increasing in thickness until it is 11 to 14 inches thick, when the ice is removed and the process repeated. Owing to the large space in the tank, all impurities in the water are driven off by the process of freezing, and settle, generally, at the bottom of the tank, where they can be flushed out before the tank is again filled to freeze another plate of ice. Also, owing to the clarifying process of freezing, ordinary potable water from any suitable source of supply can be used for plate ice making, without either filtering or distilling it. Waste and water supply connections for each compartment, of course, will be necessary.

Once the ice has formed on the sides of the metal plates, it will adhere there until removed either by mechanical means or by heat. The common practice is to turn the hot ammonia gas into the expansion coils between the plates, where direct expansion coils are used, or pump warm brine into the space between the plates when brine is used for freeezing purposes. The hot gas or brine heats the plate, the ice melts slightly at the surface, and the plate of ice thus freed from contact with the plate, floats in the water of the tank, from where it is removed and cut up, ready for storage or distribution. The freezing plates are spaced from 15 to 18 inches between, according to the thickness of the ice that is to be harvested.

Dry-Plate Ice-Making.—There are two systems of plate ice-making in use, known as the *Dry-Plate System* and the *Wet-Plate System*. In the

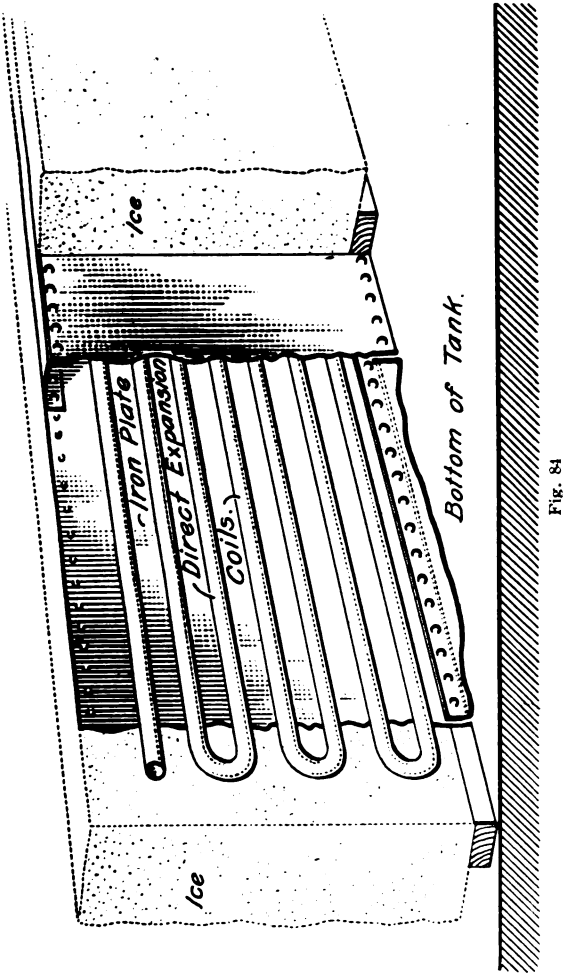


Fig. 84
Dry-Plate for Ice Making

dry-plate system, which is shown in Fig. 84, direct-expansion coils are placed between two iron or steel plates, and the heat is absorbed from the water without the aid of any intermediate agent. When the ice has formed and is ready for harvesting, hot ammonia gas is allowed to enter the expansion coils to heat them and melt the ice from the plates.

The principle condition to be guarded against in the dry-plate system is unequal freezing of the ice. If the expansion is unequal throughout the coils, the ice will not form evenly over the whole plate, but will be thickest where the ammonia is admitted to the coils, and taper out to a thin plate at the outlet. Care must also be taken that the water does not freeze so rapidly that the air cannot be liberated, or a white, "snowy" ice will result. After a few inches of ice have formed on the plates, the ammonia must be cut down or there will be danger of the coils frosting through and liquid ammonia being carried to the compressor.

Wet-Plate Ice-Making.—The wet-plate system of ice-making is shown in Fig. 85. A perfectly watertight hollow plate is filled with brine, in which is submerged continuous-weld ammonia coils. The liquid ammonia expanding in those coils cools the brine throughout to a uniform temperature, so that all parts of the plates are cooled to the same degree, insuring a uniform freezing of the ice. When the ice is of the right thickness for harvesting, the ammonia is shut off from the coils, the cold brine withdrawn, and cold water, or brine, never warmer than 60°

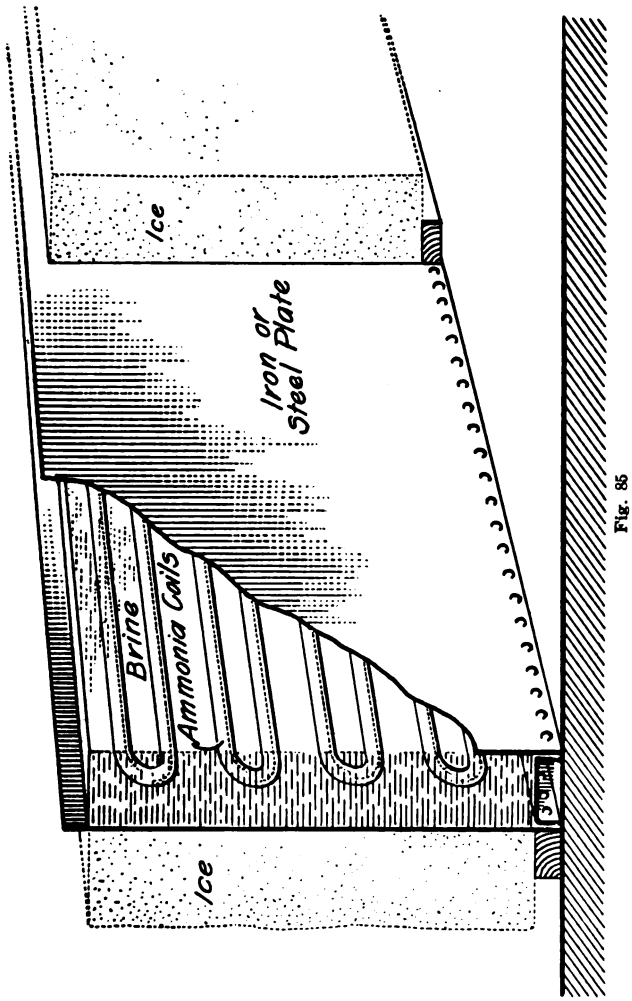


Fig. 85
Wet-Plate for Ice-Making

Fahrenheit, is pumped into the hollow cells. Water or brine warmer than 60° should not be used, as it is liable to "craze" or "shiver" the ice. Instead of changing the brine, hot gas can be allowed to enter the coils, heating the brine and loosening the ice from the iron plate.

Connections to Plate Ice-Making Tanks.—In Fig. 86 will be seen one method of connecting up the various lines to a plate-ice tank, in which four lines of pipe are used. One line is for the liquid ammonia, another for a reserve supply of liquid ammonia condensed when hot gas is used to thaw or melt off the plate of ice; the third is a hot gas line for thawing purposes, and the fourth is a suction main to the compressor. When the tanks are all ready for ice making, the liquid ammonia from the receiver is turned into the liquid line, all valves being closed on the tank connections. A beginning is made by opening valve *f* wide, then all *d* valves, and expanding through valves *a* into two plates from one valve. When the ice has been frozen the desired thickness in any compartment valves *b*, *f* and *d* are closed; and after the ice is properly tempered, the hot gas is turned on through valve *e*, opening valve *b* wide at the same time, as well as valve *c*, and permitting the condensed liquid ammonia (condensed in the expansion coils cooled by the surrounding brine), flow to the liquid reserve line, and from there to one or more compartments, re-expanding in the coils between the hollow plates, through valves *a*, then back to the compressor through the main suction line. Any modification of this system may be used to suit local conditions.

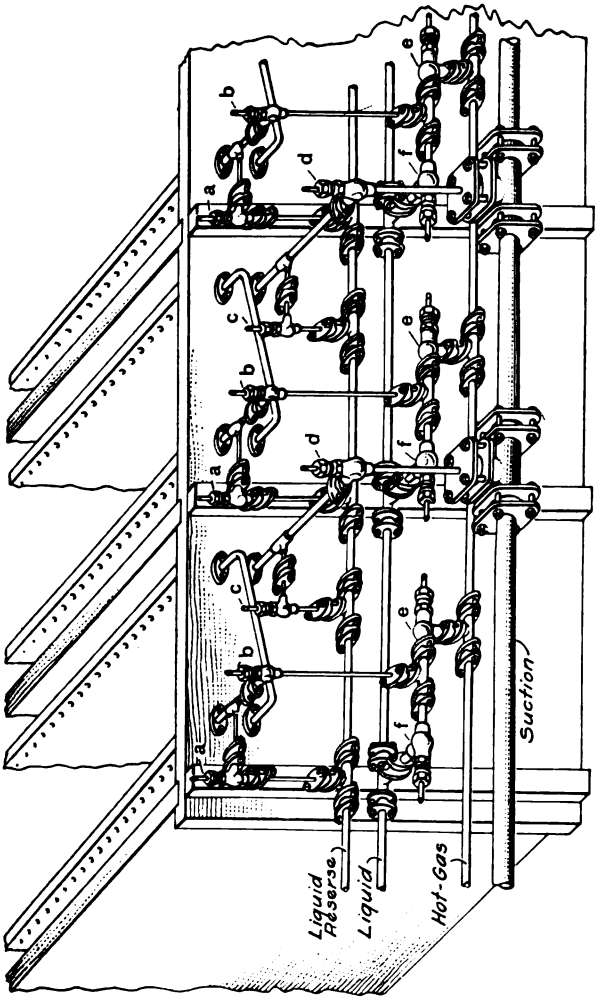


Fig. 86
Connections to Plate Ice Making Tank

Size and Thickness of Plate Ice.—Plate ice has been made in sizes as large as 12 x 20 feet, and 12 inches thick. Such a plate would weigh about 7 tons. Smaller plates of ice are usually made, however, a fair average being 10 x 12 feet, and 12 inches thick. Plate ice varies in thickness from 8 to 14 inches according to the practice of the plant where it is made. It takes from five to twelve days of continuous freezing in the average plant to produce ice of such thickness. The water in the tanks is kept in motion by means of air injection, which assists materially in the production of crystal ice. The ice so produced is hard and stores well.

Fore-Cooling Tank.—A fore-cooling tank for the storage of a sufficient quantity of water to fill one compartment of the freezing tank is always provided. This cooling tank, like the freezing tank, is best constructed of spruce or other suitable lumber, which will not impart a taste to the water, and is provided with an endless pipe coil, through which the ammonia gas passes on its return to the compressor after having been expanded in the plates. By this means a supply of cold water is always ready for refilling the freezing tanks after the ice is removed.

Harvesting Plate Ice.—The plates of ice generally have iron eye rods frozen in them for convenience in handling. When they have not, chains are slipped around the plates, while they float in the water of the freezing tank, and the plates are removed from the tank by an overhead traveling hoist, which conveys them to a tipping table conveniently arranged to

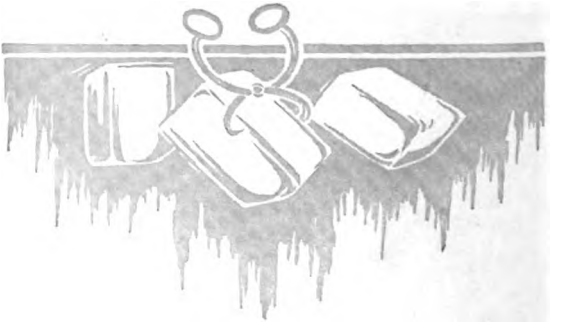
receive them, and lower them to a horizontal position, where they are cut into blocks of convenient size for handling or storage. For this purpose a steam ice cutter or an ice plow is used, which does the work very rapidly and with but slight waste. A plate of ice can be cut into suitable storage blocks in from five to ten minutes.

The Block System of Ice Making.—The block system of ice making is a modification of the plate system in which the ice is formed directly on the expansion coils, without the use of smooth steel plates, and is cut into blocks direct from the pipe coils in the freezing tank, by means of a steam ice cutter. The blocks of ice weigh from four hundred to six hundred pounds, and require but a simple hand hoist and overhead runway to remove them from the freezing tank.

The block system of ice-making, however, is not so extensively used as the plate system, although the block system has its advantages the same as every other method has. Indeed, in ice making and refrigeration, as in all other engineering systems, there is no one method which can be pointed out as the right and only method for all conditions. Each installation must be studied in the light of all surrounding facts bearing upon it, and from the fullness of this knowledge, the right system for the plant determined. Sometimes direct-expansion ammonia systems will be found best; other times the brine system. Again, the absorption system might prove the most satisfactory and economical, or the carbonic anhydride system might give the best results.

The method of refrigeration having been decided upon, the system of ice-making must be determined. Sometimes the best for the purpose is the plate system; at other times it might be some modification of the plate system, such as the block system. On the other hand, the can system might be the most economical and satisfactory, or a modification of the can system, as for instance the cell system, which partakes of the nature of both the plate system and the can system, might be the most satisfactory.

Within these pages all these systems are described, and from them the selection may be made.



CAN-ICE PLANTS

EXAMPLE OF THE CAN SYSTEM

AN illustration of a freezing tank for the can system of ice making may be seen in Fig. 87. Beginning with the tank itself, this system differs materially from the plate system. In the plate system a wood tank is commonly used, so the water will not become impregnated with iron rust, or otherwise affected. In the can system, on the other hand, a steel tank well insulated is commonly used. Three inches of cork board on the sides and four inches on the bottom, or the equivalent in other materials, all encased in wood, will make a satisfactory insulation for the purpose. Ammonia expansion coils are placed in the tank which is then filled with brine, and ice is formed in the ice cans, almost filled with distilled water, by the brine in which they are placed and which circulates freely around the cans. In order to keep the brine in all parts of the freezing tank at a uniform temperature, a brine aggitator is used to keep the fluid always in motion. The ammonia coils are run in

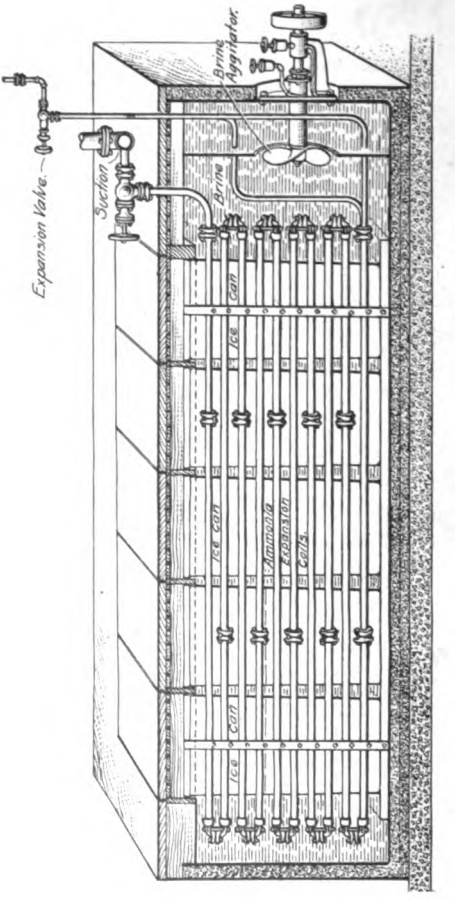


Fig. 87
Tank for Making Can Ice

parallel racks, with spaces enough between them for the ice cans to fit in. The brine serves as a cooling medium between the expansion coils and the ice cans.

In the plate system of ice making the ice forms on the polished steel plate, and proceeds uniformly in one direction, thus eliminating all impurities which are forced ahead of and away from the forming ice, thereby remaining in the water of the tank. In the can method of ice making, on the other hand, the ice forms simultaneously on all four sides and the bottom of the cans, forcing the impurities towards the center where a "core" or "feather" of snowy ice and the rejected impurities is formed.

In artificial ice making it is necessary in order to produce transparent ice, to remove the air and impurities from the water to be frozen. There are two methods of doing this. In the plate ice making system the water is aggitated by forcing fresh air through it during the process of freezing. This eliminates the air, and the freezing process rids the ice of suspended impurities. Such a product is known as "raw water ice." In the second system the water is filtered and distilled before using. This is the process used in the can method, and produces a bright clear ice with the exception of a small core or feather in the center.

Another method is to make the cans large enough so that the ice can be cut through the center or divided into the desired number of pieces, usually four, these divisions being made so the resultant blocks will have practically the same structure as plate ice; that is, it will be frozen from the one side. This method makes it possible to remove when necessary the im-

purities contained in the center or core of the original block. The center of the block may be pumped out and refilled with fresh water and frozen solid, or it may be left unfrozen if desired. In this system the water being frozen is aggitated by air or by circulation.

Ice Cans.—An ice can for making can ice is shown in Fig. 88, and the sizes, dimensions and standards adopted by the Ice Machine Builders' Association of the United States will be found in Table XXXV. The cans are made of the Best Bloom galvanized sheet, and are well riveted and soldered. All cans of 300 pounds capacity or less are made of No. 16 gauge material, and are turned over top and bottom. The 400 pound cans are made of No. 14 gauge material. All the 200, 300 and 400 pound cans have $\frac{1}{4}$ x 2 inch galvanized bands around the top, and the smaller sizes have $\frac{1}{4}$ x $1\frac{1}{4}$ inch galvanized bands around the top.

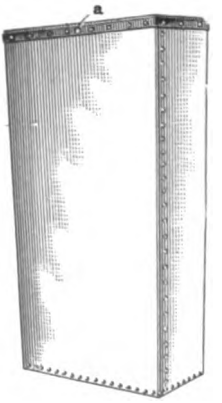


Fig. 88
Ice Cans

The ice cans are perforated at *a*, the perforations extending through the galvanized iron bands to afford a hold for the yoke used in lifting the cans from the freezing tank, and conveying them to the thawing apparatus.

Brine Aggitators.—If the brine in the freezing tank were not aggitated by some means, the local circulation would be sluggish, and the brine in contact with the ice cans after becoming heated would

not move away fast enough to bring about rapid freezing of the water. To insure a constant movement of the brine, therefore, some form of aggitator is always used. Sometimes this is in the form of a centrifugal pump, but more often a propeller blade similar to the one shown in Fig. 89, which when set in motion keeps the water so aggitated that the temperature throughout the tank is practically uniform. A partition is generally placed in the freezing tank near the aggitator so a circuit can be established, the brine flowing to the propeller blade in a steady stream, and away in a constant current. There are many modifications of this propeller used in practice, but they are all constructed and operated on the same general principles.

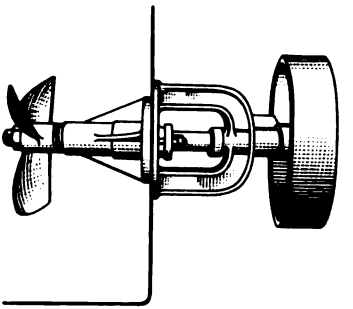


Fig. 89
Brine Aggitator

TABLE XXXV
SIZE AND DIMENSIONS OF CANS

Weight of Cake of Ice	Inside Dimensions			Lgth. Over All	Thickness of Material U. S Standard Gauge	
	Top	Bottom	Lgth.		Sides	Bottom
50 lbs.	8 x 8	7½x 7½	31	32	No. 16	No 16
100 lbs.	8 x16	7¼x15¼	31	32	No. 16	No. 16
200 lbs.	11½x22½	10½x21½	31	32	No. 16	No. 16
300 lbs.	11½x22½	10½x21½	44	45	No. 16	No. 16
400 lbs.	11½x22½	10½x21½	57	58	No. 14	No. 14

Automatic Can Fillers.—For filling the ice cans, an automatic filler similar to that shown in Fig. 90 will be found convenient. The float can be so arranged that when the water reaches the right height in the can it will be automatically shut off, and all the attendant has to do is move the filler to the next ice can.

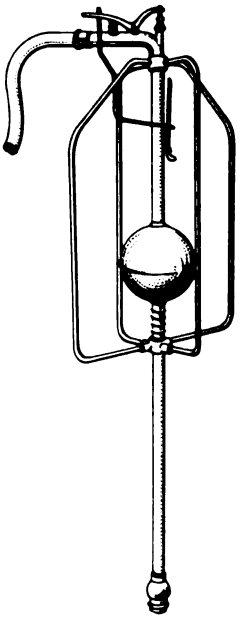


Fig. 90
Automatic Can Filler

Framework and Cover for Freezing Tank.—The framework and covers of freezing tanks are generally made of two thicknesses of 2-inch dressed lumber securely fastened together. They rest directly on top of the cans, thus not only insulating the top, but they are of sufficient weight to hold the cans in place. The framework of each opening is made of sufficient depth so that the bottom extends into the brine, thereby effectually sealing each opening, and preventing hot air from circulating beneath the framework and coming in contact with the other cans when one can is removed.

Time Required to Freeze Can Ice.—The length of time required to harvest can ice is much less than for plate ice. Whereas it takes from five to twelve days to freeze a plate of ice, can-ice can be

made in from one to four days, according to the size of block and temperature of the brine. With brine at 15° Fahrenheit, the usual temperature for can ice

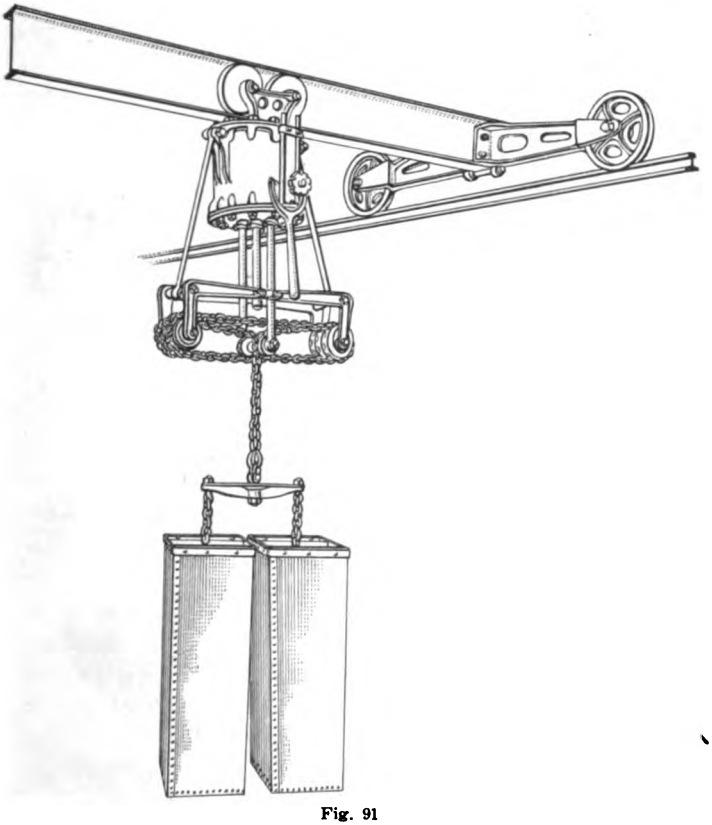


Fig. 91
Harvesting Can Ice

making, an 8-inch block will freeze solid in 24 hours; a 11-inch block will freeze solid in from 30 to 36 hours, and a 14-inch block will freeze solid in 40 to

48 hours. In practice the plant is so operated that part of the ice will be harvested each day, instead of harvesting it all one day, then waiting two or more days for the next yield.

Harvesting Can Ice.—As the blocks of ice formed in the cans are very heavy, ranging all the way from 60 pounds to 450 pounds, according to the size of cans used, allowance being made for the 10 per cent. overweight allowed for loss and trimming and the weight of the can itself, some form of lifting device must be used to take the cans from the freezing tank and convey them to the thawing device where the

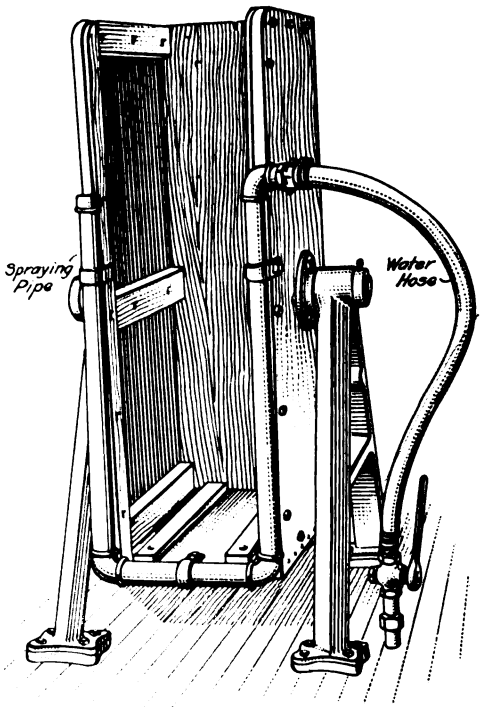


Fig. 92
Thawing Apparatus

cakes of ice are removed from the cans. Fig. 91 shows one form of traveling crane and hoist used for this purpose. Apparatus for this purpose may be had in various designs, and operated by compressed air, electricity or hand power.

Can Ice Thawing Apparatus.—From the freezing tanks, the ice cans containing their blocks of ice are conveyed by the traveling crane to a thawing apparatus where the cans are heated enough to allow the ice to slip out. The ice cans are made with a slight taper so the ice will slip out easily as soon as detached from the sides of the can. A thawing apparatus is shown in Fig. 92. When in this position a can containing ice is placed in the receptacle, which is then turned over on its axis until the open end points slightly downward. Thawing water is then turned on through the spraying pipe which sprinkles every part of the can simultaneously, causing the ice to thaw uniformly over its entire surface. The dump is generally so balanced that after the ice slides from the can it resumes its upright position ready to receive the next can. In some thawing apparatus the water is turned on automatically as soon as the dump is turned in a position to discharge the ice, and is turned off automatically as soon as the dump resumes its upright position. Again, some thawing devices are mounted on revolving turn-tables so the ice can be discharged in any direction; and still others have drip pans to catch the thawing water, thereby keeping the floor dry.

Purifying Water for the Can System.—As was previously pointed out, in order to obtain abso-

lutely pure crystal ice by the can system, a complete distilling and filtering process must be employed. Filtration without coagulant will give a clear water, and evaporation in the process of distillation makes the water absolutely pure. The steam is then condensed and cooled ready for use in the cans. All air must be expelled from the water, otherwise it will freeze into opaque or so-called "snow-ice."

In the can system of ice-making, special water purifying apparatus is required. The steam generated in the boiler is first used to drive the compressor in case of a compression system; or to heat the strong liquor in the generator in the case of an absorption system. From the compressor the exhaust steam passes through an oil extractor on its way to the steam condenser. The steam condenser may be the usual type of steam condenser, or may be designed on the same principle as the ammonia condenser, being a series of pipes over which cooling water is allowed to flow, while the steam is confined within. If the exhaust steam is not sufficient in amount to make the required quantity of ice, enough live steam is supplied to the steam condenser to make up the deficiency. The water resulting from the condensing of the steam passes to a skimmer where any oil which might have passed the oil extractor is removed. From the skimmer the water goes to the re-boiler at the bottom of which is placed a small steam coil by means of which the water is kept boiling and the air contained in it expelled. The water then passes to a flat cooler, an apparatus similar to a condenser, where its temperature is reduced to that of the cooling water available. Thence it is conducted to the

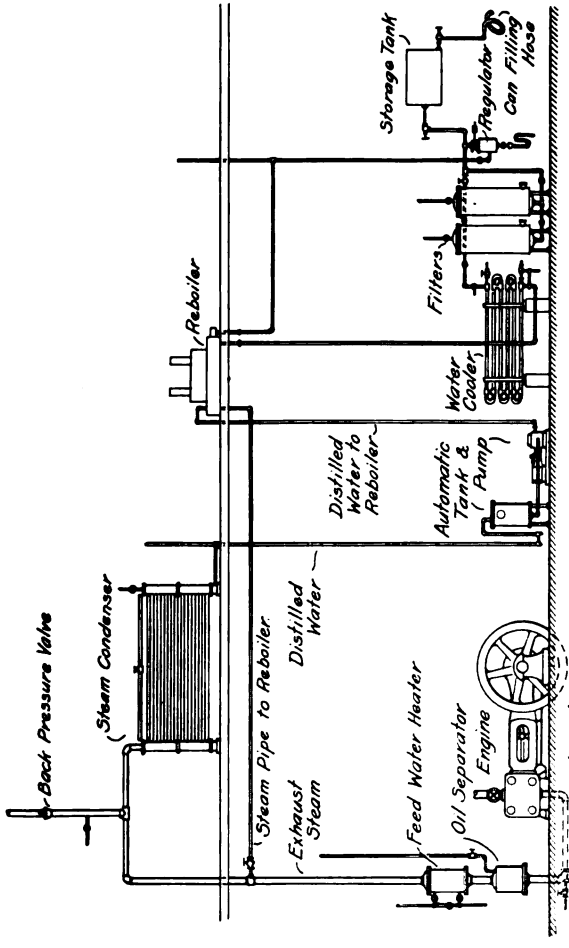


Fig. 88
System of Water Purification

filters which are furnished in duplicate, so that one may be shut off and cleaned without interfering with the operation of the plant. From the filters the water passes to the cold-water storage tank which contains the return ammonia expansion coils or suction pipe to the compressor. By the use of this coil, the distilled water is reduced almost to freezing temperature before going into the freezing cans.

A system of water purification for can ice-making is shown conventionally in Fig. 93. This shows merely the relative arrangement of the several parts but not necessarily their various elevations. The steam condenser can be lower if necessary, but it is well to have the re-boiler sufficiently high to give the head necessary to operate the regulator as well as to have the head necessary to force the distilled water through the filters.

Atmospheric Steam Condensers.—Atmospheric steam condensers are made on the same general principle as atmospheric ammonia condensers. They differ in these few details: That steam condensers are made of larger pipe, 2-inch, 2½-inch, and 3-inch pipes being used for this purpose; and the pipes are galvanized to keep the condensed water as free from rust and scales as possible.

Atmospheric steam condensers are made on the counter-current principle. That is, steam enters at the bottom of the coil where it comes in contact with pipes over which the warmest water is flowing, and rises to the top where fresh water comes in contact with the condenser pipes. The coils are not made very high, usually being restricted in height to seven loops.

Double-Pipe Exhaust Steam Condenser.—Some steam condensers are made on the double-pipe principle. One of this type is shown in Fig. 94. It consists of a double coil connected by return bends at the ends. The exhaust steam enters the header at the center of the coils, passes through the spaces formed between the inner and outer pipes where it is condensed by the water flowing through the inner pipes, and out at the bottom into the skimmer.

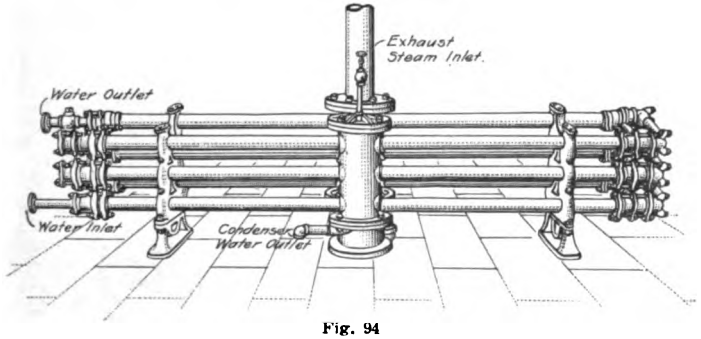


Fig. 94
Double-Pipe Steam Condenser

Double-pipe exhaust steam condensers are made with outlet pipes $2\frac{1}{2}$ inches in diameter, and the inner or water pipes $1\frac{1}{4}$ inches in diameter. The size and capacity of these coils can be seen in Table XXXVI:

TABLE XXXVI
SIZE AND CAPACITY OF DOUBLE-PIPE STEAM CONDENSERS

Capacity Tons Ice Making	Number Pipes High	Length of Coil	Weight
2	3	10	1500
5	3	15	1750
7½	3	20	2000
10	6	15	3000
15	6	20	3600
20	9	20	5200

Surface Steam Condensers.—In Fig. 95 is shown the interior of a surface steam condenser. Cooling or condensing water enters the chamber at the right end of the cylinder, passes through the lower group of tubes to a chamber at the left end of the cylinder, then back to the right end of the cylinder through the upper group of tubes, then away from the condenser entirely. The exhaust steam enters the shell at the top, is condensed by coming in contact with the water-filled tubes, and flows out of the

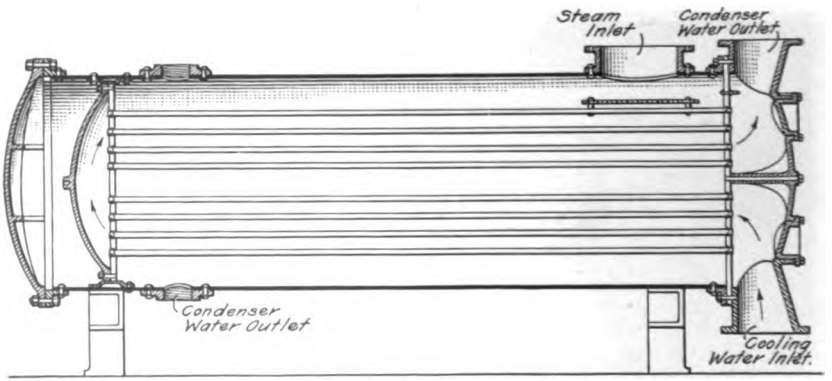


Fig. 95
Surface Steam Condenser

bottom opening of the shell. The tubes are made of seamless-drawn brass, and are expanded into bronze tube heads at both ends. Provision must be made for the free expansion and contraction of the tubes under changes of temperature, and this is accomplished by means of a sliding tube-head through which the tubes can freely slide.

Skimming and Re-Boiling Tanks.—The object of skimming and re-boiling the distilled water is to draw off all air and gas, and skim off any oil or grease remaining in the water. A skimming and re-boiling tank is shown in Fig. 96. In this the boiling of the water by means of heat from the submerged steam coils agitates the surface of the water, and brings all oil and grease to the top. The funnel at one end skims off this surface scum, and naturally the floating particles tend to flow towards this outlet.

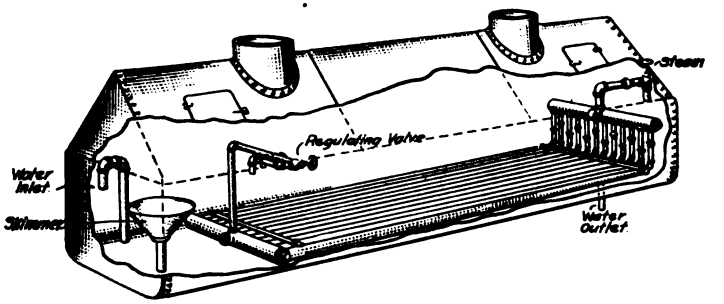


Fig. 96
Skimming and Re-Boiling Tank

The water inlet is near the skimmer so that impurities will be deposited close to the point of escape. Either live steam or exhaust steam can be used for the steam coils, and the water of condensation from the steam coil may be conducted away, or allowed to escape into the re-boiler tank through perforations in the pipes, as is sometimes done.

Sometimes the skimming tanks and re-boiling tanks are separate. Fig. 97 shows a skimming tank which is used separate from the re-boiler, and Fig. 98 shows a cylindrical type of re-boiling tank fitted

with a spiral coil. This tank shows in good-size detail the regulating valve in the re-boiler. The object of this regulating valve is to prevent air being drawn into the water going to the filters. The operation is simple. When the re-boiling tank is full of water, the valve on the water outlet is wide open. But as the water line begins to fall in the re-boiling tank, the balanced float falls with it thereby gradually closing the valve, and entirely closing it before the water level reaches a point where air would be entrained and carried with the water to the filters.

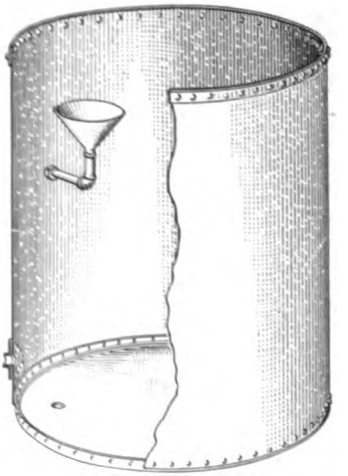


Fig. 97
Skimming Tank

Filters.—Any good type of water filter may be used for the clearifying of the distilled water before it goes to the cooling tank. Usually, however, they are made of galvanized sheet material fitted with perforated plates and filled with charcoal and quartz sand. The ordinary pressure filter for house-hold use is not largely employed for this purpose, although it may be, nor is a coagulant used in the filters, as it is clearness, not bacterial purity that is required of the filters. As a matter of fact, the "filters" are more of the nature of strainers than real filters.

Distilled-Water Cooling Tank.—One form of cooling tank for distilled water is shown in Fig. 99. In it is immersed a coil through which ammonia from the freezing tank passes on its way to the suction end of the compressor cylinder. This tank contains a supply of water at low temperature from which is drawn the pure water necessary to fill the cans.

A different type of distilled water reservoir is shown in Fig. 100. This is cylindrical in shape, contains a spiral coil and an aggitating apparatus to prevent the water from freezing to the coils when at a low temperature.

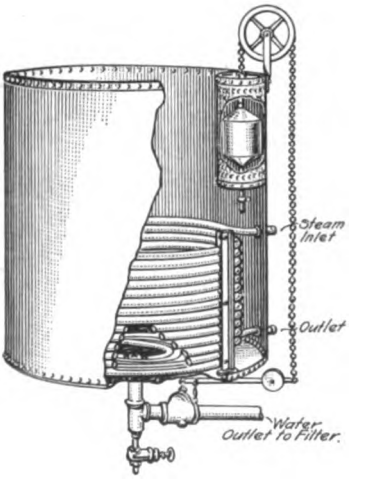


Fig. 98
Cylindrical Re-Boiler

Storage of Ice.—In the manufacture of ice it is well to have an ice storage room with a capacity of from two to four weeks run. This will permit the plant to be started several weeks in advance of the ice season, and will tide over those periods when it is necessary to shut down the plant temporarily for repairs. Ice made by the plate method resembles natural ice in appearance and keeping qualities, while ice frozen by the can method has a more or less porous structure, especially at the core, in the middle of the block, and consequently melts more quickly than

plate ice. Owing to this fact, a storage room for plate ice needs no refrigerating system to keep the ice from melting, while storage rooms for can ice require artificial refrigeration to keep the ice from melting. One and one quarter inch pipe is generally used for this purpose, and 1 lineal foot of pipe of this size will be sufficient for each 10 cubic feet of space in a well-insulated storage room.

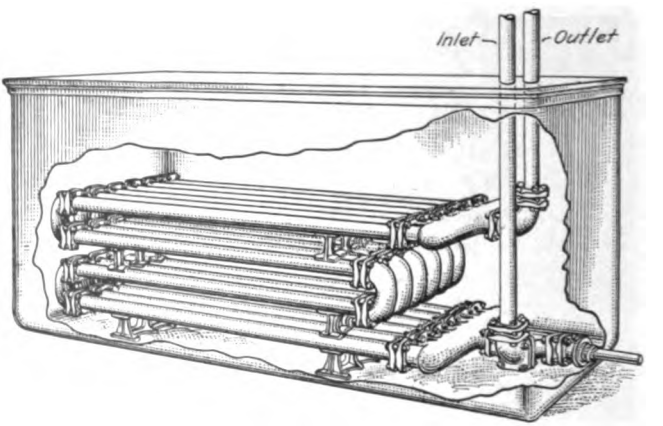


Fig. 99
Cooling Tank

The storage rooms should be kept at a temperature of about 28° Fahrenheit. If the temperature of the room goes above 30° or 32° Fahrenheit, the ice will be liable to melt; while if the temperature falls below 28°, the ice is liable to check. Alternate thawing and freezing will freeze the ice into one solid mass, unless the precaution is taken to separate the different layers with strips of wood, and pack the blocks of the different tiers with space between one another.

Comparison of Can and Plate Methods.—Which method of ice-making, the can or the plate system, will prove the more economical and satisfactory will depend in each case on local conditions; and the local conditions will often determine whether the compression or the absorption system of refrigeration should be adopted, which in turn will determine the method of ice making. As a rule it may be said that plate-ice plants are considerably more expensive to install, but under favorable conditions are more economical of operation than can ice plants.

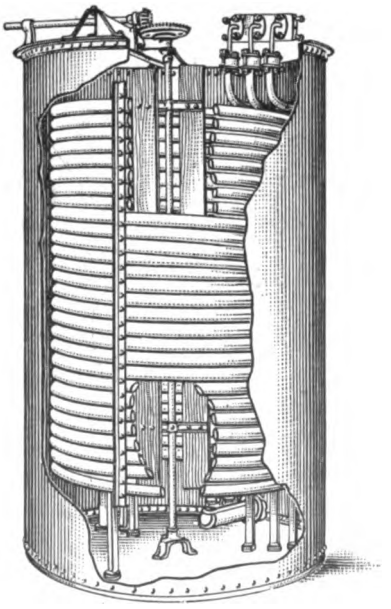


Fig. 100
Cylindrical Water Cooler

If a large quantity of exhaust steam is available for ice making, which otherwise would be wasted, the absorption system of refrigeration and the can method of ice making would no doubt prove the most satisfactory, and by far the most economical, for very little power is required in those two processes, although heat, and heat in the particular form of steam, is necessary for

both of these. The exhaust steam after distilling the ammonia in the generator of the absorption system could be condensed and used after being further purified, for making the can ice.

For plate ice-making, steam is not necessary. Power is all that is required and that can be supplied by water, gas, steam or electricity. Steam is not even necessary for the water used in the manufacture of the ice, ordinary potable water being suitable for the purpose. The ice made by the plate system is denser and has better preserving qualities than can ice, so if the ice must be stored for a considerable period of time, the plate ice will be found the better for the purpose, and can be stored without refrigeration.

CELL BLOCK SYSTEM OF ICE-MAKING

The cell block system of ice-making combines to a great extent the best features of both the plate system and the can method of making ice. The ice or water is frozen in a large tank filled with water the same as in plate ice-making, therefore distilled and filtered water is not necessary. At the same time the ice is formed in molds and the harvest yields blocks of uniform size convenient for handling. Like in plate ice-making, any form of power, water, electric or gas engine can be used.

The cell block system of ice-making is shown in perspective in Fig. 101. In a large tank are fitted continuous coils crossing each other alternately at certain intervals so as to form spaces or cells. In these spaces are fitted galvanized iron cells made of

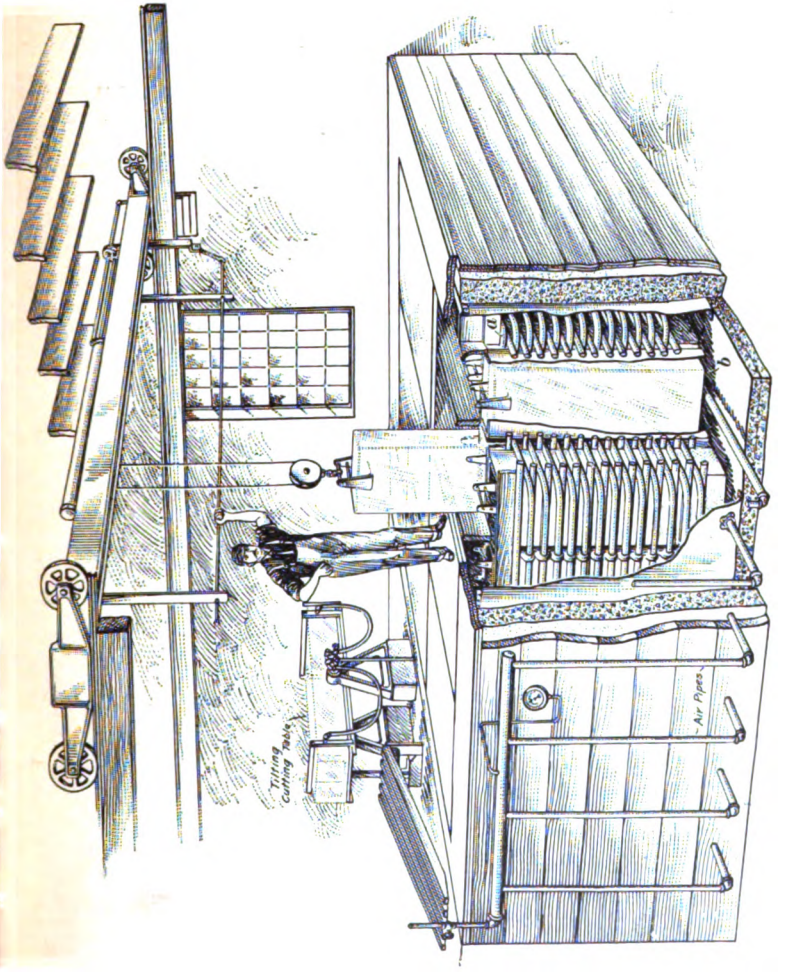


Fig. 101—Cell-Block System of Ice Making

a size to just fit the spaces. These cells are open both at bottom and at top, and when the plant is ready for freezing, the water stands a few inches above the top of the cells. Unlike in the can system, circulation is possible through the cells while the ice is forming, and this circulation is made positive by air which is forced in at low pressure at the bottom of the tank, at the center of each cell space. The freezing process forces all impurities towards the center of the cell, and the rising air bubbles carry the impurities to the surface of the water and into an overflow which carries the water through a filter, and into a cold storage tank to be used over again.

Ammonia Coils for Cell Block Tank.—The ammonia expansion coils for a cell-block freezing tank are shown in Fig. 102. On account of the crossing of the coils surfaces are formed which freeze the water in the cells uniformly from all four sides. When the blocks are formed and ready for harvesting, the ice is freed from the metal surfaces of the cells by discharging hot gas from the compressor cylinder through the coils.

Ice-Forming Cells.—Ice-forming cells for the cell block system of ice making are shown in Fig. 103.

Into the rectangular spaces or subdivisions formed by the coils are permanently fixed there cells or freezing chambers. The walls of the cells are in close proximity to the coils, substantially in contact therewith, the coils being arranged to cover the sides of the cells uniformly between their ends. The cells are made of galvanized iron, wide open at both ends

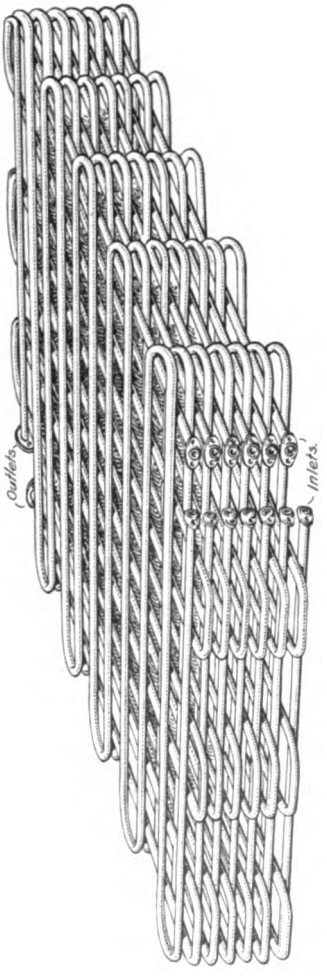


Fig. 102
Ammonia Coils for Cell-Block System

to the interior of the tank and constitute a tube with smooth interior and without taper. They are arranged a few inches above the bottom of the freezing tank, so as to leave a free space beneath them for the circulation of water and for the admission of pipes supplying air. It is of course understood the tank is filled with water and the coils and cells are immersed therein merely subdividing this body of water into ice block size, the cells being open full size top and bottom and the ice forming the depth of the freezing coils only. This leaves a portion of water unfrozen above and below the blocks of ice when finished.

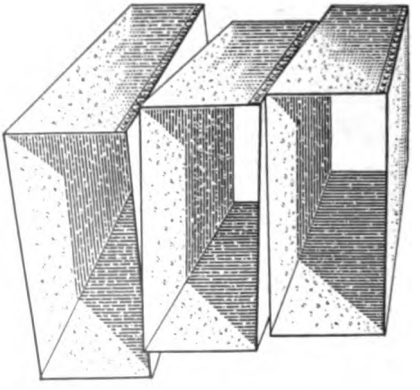


Fig. 103
Ice Forming Cells for Block System

The blocks are 11 x 22 inches, and the freezing, tempering, thawing and harvesting of a tank is accomplished in 48 hours. The blocks of ice are about the size of corresponding can-ice blocks.

Water Circulation in Cell-Block Ice Making.—As a rule, the air agitation described in the foregoing paragraph is sufficient to make ice of good quality for a long time without cleaning of the tanks, as the water space above and below the cells is suffi-

cient to hold the cast-off impurities without becoming concentrated. Where the water supply is heavily laden with salts and the unfrozen water becomes concentrated before the ice blocks are entirely frozen, a water circulation is provided for. Each tank has several water inlets at its bottom and a slotted overflow pipe at its top on the opposite side of tank to water inlets. Before the ice blocks in a tank nearly ready to harvest freeze up entirely, a small centrifugal pump interchanges the unfrozen water in the center of ice blocks, removing the water laden with impurities and substituting fresh, clean water. The water circulating pump takes its suction from an insulated underground basin containing clean ice water. The water rising in the cells establishes a current which carries the impurities to the overflow pipe. This overflow water then flows by gravity through a filter where it is purified and thence is piped to the ice water basin.

Utilizing Waste Power for Ice Making.—The manufacture of ice and the cooling of storage rooms, or the supply of refrigeration from a central plant, can be carried on most economically by public service corporations such as central heating companies and electric light and power companies.

Corporations of these natures have their greatest demand for power in the winter months when the least power is required for refrigeration; and the least demand for power in the summer when ice and cold storage are in the greatest demand.

Central heating plants can combine heating and refrigeration to the best possible advantage, thereby

running at full capacity the year round instead of only a few months in the year. Electric light and power companies, likewise have the greatest demand for power during the long nights and cold weather of the winter months, with a corresponding decrease in summer, so the manufacture of ice and supplying of refrigeration offers to this industry a promising field.

Electrical engineers are alive to this opportunity, and at a recent convention, went on record, unanimously, as recommending the combining of refrigeration and ice-making with electric light and power, as a means of increasing their field of usefulness by cutting down the cost of producing electric current.

USEFUL TABLES AND INFORMATION

The following information and tables are from information furnished by the manufacturers of refrigeration machinery in their various publications.

ERECTING, CHARGING AND TESTING OF PLANT

ERECTING PLANT.—The first thing is to seek the Manager and become acquainted with him, get his permission to go over the buildings, so that you will become familiar with them. Then distribute the bulky material where it belongs, put all the fittings of one size together in one place.

Tack blue prints up in conspicuous places for convenient reference. Follow drawings as far as possible, and when changes are advisable they should be authorized in writing by the purchaser, as well as the home office, provided they are of any importance.

Have no arguments—leave it for the home office to settle all matters arising, causing dissatisfaction or misunderstanding on either side.

Stand all pipe on end and hammer well, so as to remove grit, scale, etc.

When all connections are made pump 150 pounds air pressure on the entire plant by shutting off the main suction valve on machine—remove small flange on suction manifold for drawing in the air.

Have ample water going around the compressor and allow considerable oil to drop in with the air, so as to keep the machine cool and lubricated—caution is necessary here—the machine can be kept running as slow as it will while looking after the various joints, etc.

After you have everything reasonably tight, put 200 pounds pressure on the condenser alone; blow out each coil separately. Do this by breaking connection on the liquid line between condenser and receiver. After condenser is clean, connect up the liquid line and blow out receiver and oil trap, then allow machine to continue slowly, keeping up about 200 pounds pressure, and blow out with air each coil separately in the brine tank.

If there are any direct expansion coils, the same course will apply. By holding the hand in front of the opening you can readily detect if there is any scale blowing out.

Be sure and keep the low pressure gauge closed up all this time, then pump 300 pounds pressure on the entire system, going over every joint with a candle and you will easily discover if there are any perceptible leaks.

Then mix up a soap suds and go over every joint. It pays, however, when the 300 pounds pressure is on to let the plant remain quiet for a few hours and your gauge will show if there are any bad leaks.

The pressure should remain on for at least twelve hours, and can stand a loss of from five to ten pounds during that time.

After this, allow the air to blow out and pump about a 10 or 15-inch vacuum on the system; to do this, open your main suction valve, close the main discharge valve and remove small flange on the discharge manifold, being careful to see that there is a discharge opening, then connect a drum of ammonia to the discharging valve near the receiver and allow a few pounds of ammonia to go into the system. This will produce ammonia gas in every part of the system, and you should pump up another pressure of 300 pounds so if there are any minor leaks you can detect them. It will pay to leave this pressure on the coils for another ten or twelve hours, after which allow the air to blow out again and put a vacuum on the system of from 28 inches to 30 inches, or keep on pumping until there is no more discharge. The most simple way of telling this, is to put your finger over the discharge hole and if you can keep it there there is nothing more to remove.

Then, to charge the plant, close up every valve on the entire system, except ammonia condenser, and shut off valves on the brine tank, open up one to three expansion valves on the brine tank, also the charging valve connected to the liquid line near the receiver, then open slightly the valve on the ammonia drum, which should lay on an incline of about 3 inches.

After you have about five or six pounds in the system start up machine slowly. It will not make any material difference whether you pump this gas in at 5 or 20 pounds back pressure. Keep on pumping until your drum is empty. Let the machine run slow as you note the back pressure is going down. Pump a 5-inch vacuum on each drum and be careful to test and weigh each drum before and after removing the ammonia from same.

Keep on in this way until the plant is charged, and as your brine becomes colder turn on more coils, but always try and keep the ammonia coming over sufficiently cold, so as not to overheat the machine.

There is nothing to be gained in trying to expand through all of the coils and cool down a lot of warm brine at one time.

Any of the valves can be packed while the pressure is on by turning the stem to the left up against the back seat.

The gas can be removed from one section of the condenser or brine tank and a pipe or fitting removed and replaced.

The machine should receive plenty of oil all this while; the amount can be diminished every day if everything is in good working order, the compressor and rod kept cool, very little lubricating is necessary.

The valves on the machine are easily regulated and will work noiselessly at any back pressure desired.

To give the discharge valve less lift, turn the stem to the right, and to give it more life or opening turn the stem to the left; to give the middle and suction valves more opening turn the stem to the right, and less opening turn the stem to the left.

Watch all parts of the machine. It should operate perfectly noiseless in less than four days' running.

Keep all bearings snug and tight. Do not carry too excessive a back pressure for a few days, but increase gradually.

Keep ample water going over the condensers thoroughly distributed.

Any further information desired can be secured at the home office.

Packing the Machines.—Pack the machine with any ordinary packing for testing out with, then remove the old packing and valves and clean all off thoroughly and replace them carefully.

The packing should be inserted into the stuffing box as follows:

First, solid ring, three or four section rings, then solid ring and then the oil lantern. This should come just opposite the relief pipe and ammonia expansion valve, then a solid ring, after which two or three sectional rings and then another solid ring.

For the outside stuffing box split a solid ring in two and insert so as to break the joints and you are ready for pumping ammonia.

This stuffing box should be watched closely so as to prevent its getting too hot, as burnt packing will always give trouble. It can easily be kept cool with sufficient oil and a little ammonia around same.

The relief valve connected to the pipe leading from the center of the stuffing box to the suction side of the machine should always be slightly open.

OPERATION AND CARE OF REFRIGERATION PLANTS

Refrigerating Plants.—A refrigerating plant requires but little more care than an ordinary power plant. The care of the engines, boilers, pumps, and all connections is exactly the same.

The additional work required centers in the handling of the ammonia and the ammonia compressor.

There are one or two good general rules which can be given for handling the ammonia. First, carry as low a condenser pressure as possible, get the coldest and best water available, and use as much of it as you can economically. Water always costs something, if it is only the cost of pumping.

If the water has to be bought, balance the cost of the water against the cost of the fuel, and run the plant on an all-around economical basis; remembering, the lower condenser pressure the less the load will be on the engine, and the less fuel will be required to drive it.

Keep the condenser coils clean.

Draw off the oil from the oil traps at some stated time, regularly, say once a week, and at the same time open the air vent on the ammonia condenser and blow out such foul gas as may have collected.

Carry as high suction pressure as possible. The less difference there is between the suction pressure and the condensing pressure, the more economically the plant can be run.

The higher the suction pressure the greater the weight of the ammonia circulated through the plant, and the greater the capacity of the compressor.

The only limit to the suction pressure is the temperature of the brine in a brine plant or of the rooms in a direct expansion plant.

Study carefully the table of boiling points of ammonia, and carry such a suction pressure that the boiling point of the ammonia will be about 10° F. below the temperature you are handling.

For ordinary work, the following tables of suction pressures are correct:

TABLE XXXVII

SUCTION PRESSURES AND TEMPERATURES

Lowest Temperature to be Maintained	Suction Pressure (Gauge)
Deg. F.	Lbs.
— 5	5
0	10
+10	15
+15	20
+20	25
+25	30

Keep the plant fully charged with ammonia. It is not necessary to stop the machine to charge in new ammonia. Connect the full drum to the charging pipe, shut off the valve between the charging connection and the liquid receiver and open the charging valve and the valve on the drum. Expand from the drum until the suction gauge shows a vacuum. Run the machine slowly as the gauge pressure falls below zero. When a vacuum is reached, shut the charging and drum valves, open the valve at the foot of the liquid receiver slowly, and speed up the machine, as the suction pressure rises, until the speed and pressure have regained the normal condition.

Don't start the compressor without knowing the water is running freely over the ammonia con-

denser, and that every valve is open on the high pressure side, right down to the expansion valve.

Don't pump a vacuum unnecessarily. Open the suction valve as soon as the engine will turn over the centers, and open the expansion valve as soon as the gauge indicates a pressure a little below the regular suction pressure.

Don't stop the compressor until the expansion valve has been shut and the suction pressure pumped down to within a few pounds of zero.

If the compressor is going to stand for an hour or more, shut the suction valve and tighten the piston rod packing. Be sure to slack off the packing when starting up.

Don't break an ammonia joint before opening some blow-out valve (such as the charging valve or valve on the oil trap) to make sure the pressure is all out.

Don't expect a new ammonia joint to be tight. Test it with air and know that it is tight before you put on a pressure of ammonia.

Don't fail to pump all the air out of the system after making repairs.

Don't blow out ammonia in a confined place. When blowing out oil, foul gas or ammonia, pipe it off to some little distance from the valve. If you let it drive you away from the valve you will not likely get back to shut it off.

Don't use any more oil in the ammonia system than is absolutely necessary, and see to it that the oil used is purely mineral.

Don't use any more oil in the steam cylinder than is absolutely necessary.

Don't use poor quality of oil in cylinders.

Don't forget your oil separator. Keep it constantly drained of dirty water and oil.

Don't use any more water than necessary on steam condenser.

Don't neglect condenser coils. Keep them clear of scale.

CARE OF ICE PLANTS

Care of Ice Plants.—Besides the general care of machinery and the ammonia system, the ice making engineer must carefully watch over the distilled water system; and here, if anywhere, "eternal vigilance is the price of—success."

Don't use any more oil in the steam cylinder than is absolutely necessary. From two to four drops a minute will answer for most engines, if the oil is good—and it ought to be. See that the oil separator is constantly drained of dirty water and oil.

Use as little water on the steam condenser as possible, just enough to condense the water required to fill the ice cans. Keep the condenser coils scaled off clean. The hotter the distilled water comes from the condenser, the less steam it will require in the re-boiler, and the less likelihood there is of condensing, together with the steam, other free gases passing into the steam condenser along with the exhaust steam. Always allow a slight amount of exhaust steam to escape at the relief valve to carry off foul gases.

Use a closed coil in the reboiler in preference to a perforated coil. A perforated coil often gives the appearance of boiling to the water in the tank when

the temperature is still below 212°. Keep the re-boiling tank up to 212°, and run the waste steam from the re-boiling coil into the steam condenser.

See that the skimmer overflows at regular intervals.

Blow out the cooling coil regularly. It may be once a day, once a watch, or oftener, as required by the nature of the water handled, but have some regular time to attend to it. The cooling coil is a most important part of the plant, and should be supplied with a liberal amount of the coldest water available. Every unit of heat extracted from the water while passing through the cooling coil is one less for the ammonia to handle.

Wash out filters regularly.

Draw the ice at regular intervals, day and night, so as to keep a constant supply of heat coming to the machine. Draw the ice in rows across the coils in the tank, rather than along the coils, so that each coil will get a regular supply of heat.

Carry the temperature of the freezing tank as high as possible, as the longer the ice takes to freeze the clearer it will be. The higher the temperature of the brine the less heat it will be necessary to extract from the water to be frozen.

Keep the suction pressure as high as possible, considering the temperature in the freezing tank.

Watch carefully the circulation of the brine in the freezing tank. More plants fall short of their capacity by reason of poor circulation than from any other cause. When the frost comes back to the compressor with a comparatively low back pressure and

high brine temperature, nine times out of ten it is the circulation that is at fault.

Keep the dipping bath or thawing device at as low a temperature as possible, just warm enough to release one block before the next is ready.

Keep the boilers clean and keep a close watch on the water level in the boiler. A high water level means a priming boiler, and a priming boiler means bad ice.

Dirty boilers are expensive to run. Mr. W. S. Hutton, in "STEAM BOILERS," gives the following table showing the loss of fuel due to scale in boilers. The loss of fuel caused by scale in steam boilers may in a general way be averaged as follows:

Scale $\frac{1}{32}$ inch thick, causes a loss of 2% of fuel.
Scale $\frac{1}{16}$ inch thick, causes a loss of 4% of fuel.
Scale $\frac{1}{16}$ inch thick, causes a loss of 9% of fuel.
Scale $\frac{1}{8}$ inch thick, causes a loss of 18% of fuel.
Scale $\frac{3}{16}$ inch thick, causes a loss of 27% of fuel.
Scale $\frac{1}{4}$ inch thick, causes a loss of 38% of fuel.
Scale $\frac{3}{8}$ inch thick, causes a loss of 48% of fuel.
Scale $\frac{1}{2}$ inch thick, causes a loss of 60% of fuel.
Scale $\frac{5}{8}$ inch thick, causes a loss of 74% of fuel.
Scale $\frac{3}{4}$ inch thick, causes a loss of 90% of fuel.

Carbonates of lime and magnesia are precipitated by heat at from 160° F. to 240° F., and can be separated from the feed water by a good heater.

Sulphates of lime will not precipitate at less than 300° F., and can only be separated by a live steam purifier or by using some chemical compound as a coagulant. The compound should be mixed with the feed water before it passes through the heater.

Space Required for Can Ice Plants.—From Table XXXVIII, an approximate idea of the space required for a given size plant may be readily obtained. It must be understood that these dimensions can be varied greatly to suit local conditions.

TABLE XXXVIII
SPACE REQUIRED FOR CAN ICE PLANT

Daily Capacity	Dimensions	
	Width	Length
5 tons	30 feet	56 feet
10 tons	35 feet	73 feet
15 tons	37 feet	78 feet
20 tons	40 feet	85 feet
25 tons	42 feet	95 feet
30 tons	42 feet	107 feet
35 tons	42 feet	117 feet
40 tons	49 feet	120 feet
50 tons	49 feet	135 feet
60 tons	54 feet	150 feet
80 tons	59 feet	154 feet
100 tons	73 feet	160 feet

Rules and Approximate Pressures Generally Used.—One British Thermal Unit (B. T. U.) is the quantity of heat required to raise one pound of water at 32° F. to 33° F. or the amount of heat that must be extracted from one pound of water at 33° F. to reduce it to 32° F.

The latent heat of ice is 142 B. T. U. That is to say, one pound of ice at 32° F. will require 142 B. T. U. to melt it into water at 32° F., or 142 B. T. U. must be extracted from water at 32° F. to freeze it into ice at 32° F.

One ton of refrigeration is the amount of heat absorbed by the melting of 2,000 pounds of ice at 32° F. into 2,000 pounds of water at 32° F. or the amount of heat that must be extracted from 2,000 pounds of water at 32° F. to reduce it to 2,000 pounds of ice at 32° F. or $2,000 \times 142 = 284,000$ B. T. U.

TABLE XXXIX

APPROXIMATE COST OF OPERATING ICE FACTORIES

Tons Ice per Day	Engineers $1.50 to $5.00 per Day		Oilers $1.25 per Day		Firem'n $1.25 per Day		Tankmen & Laborers $1.00 per Day		General Helpers $1.25 per Day		Coal 15 cts. per Cwt. or $3.00 per Ton		Oil, Waste, Lights and Sundries	Daily Oper. Exp.	Ice per Ton
1	2	$3.00	..	....	..	....	..	....	..	....	500	$0.75	$0.50	$4.25	$4.25
2	2	3.00	..	....	..	....	..	....	..	....	1,000	1.50	.50	5.00	2.50
4	2	3.00	..	....	..	....	1	$1.00	..	....	2,000	3.00	.50	7.50	1.88
6	2	3.50	..	....	..	....	1	1.00	..	....	2,700	4.05	.50	9.05	1.51
10	2	3.50	..	....	..	....	1	1.00	..	....	4,500	6.75	.75	12.00	1.20
5	2	3.75	..	....	..	....	2	2.00	..	....	6,700	10.05	1.00	16.80	1.12
20	2	3.75	..	....	..	....	2	2.00	..	....	8,000	12.00	1.00	18.75	.94
25	2	4.00	..	....	2	$2.50	2	2.00	..	....	8,400	12.60	1.10	22.20	.89
30	2	4.00	..	....	2	2.50	2	2.00	..	....	9,500	14.25	1.25	24.00	.80
35	2	4.00	..	....	2	2.50	2	2.00	..	....	10,800	16.20	1.50	26.20	.75
40	2	4.50	..	....	2	2.50	3	3.00	..	....	11,500	17.25	1.75	29.00	.73
50	2	4.50	..	....	2	2.50	4	4.00	..	....	14,300	21.45	2.00	34.45	.69
60	2	5.00	1	$1.25	3	3.75	4	4.00	..	....	16,000	24.00	2.25	40.25	.67
75	2	5.00	1	1.25	3	3.75	4	4.00	1	$1.25	20,000	30.00	3.00	48.25	.65
100	2	5.50	2	2.50	4	5.00	6	6.00	1	1.25	25,000	37.50	4.00	61.75	.62

One pound of ammonia expanded at 15 pounds gauge pressure, will absorb 555 B. T. U.

Proportions of expansion piping are based on a suction pressure of 15 pound gauge.

Proportions of brine piping are based on brine of 80° density on the salometer, weighing 75 pounds cu. ft. The temperature of the returning brine is assumed to be 6° higher than the temperature of the outgoing brine.

TABLE XL

APPROXIMATE TEMPERATURES, PRESSURES AND DISPLACEMENT

Lowest Temp. to be Maintained	Approx. Temp. of suction gas	Suction Pres. Gauge	Cu. Ins. of Cyl. Cap. per Min.
Deg. F.	Deg. F.	Lbs.	
— 5	—17	5	10,700
0	— 8	10	9,000
×10	0	15	7,500
×15	× 6	20	6,000
×20	×11	25	5,400
×25	×17	30	4,800

Cooling Coils.—The number of cubic feet of well insulated space per ton of refrigeration, for small rooms up to 1,000 cubic feet capacity:

If held at zero F., 200 cubic feet per ton.
If held at 5 degree F., 400 cubic feet per ton.
If held at 10 degree F., 800 cubic feet per ton.
If held at 20 degree F., 1400 cubic feet per ton.
If held at 32 degree F., 2000 cubic feet per ton.
If held at 36 degree F., 2500 cubic feet per ton.

For rooms from 1,000 to 10,000 cubic feet capacity:

If held at zero F., 600 cubic feet per ton.
If held at 5 degree F., 1200 cubic feet per ton.
If held at 10 degree F., 2500 cubic feet per ton.

If held at 20 degree F., 4500 cubic feet per ton.
If held at 32 degree F., 6000 cubic feet per ton.
If held at 36 degree F., 8000 cubic feet per ton.

For rooms over 10,000 cubic feet capacity:

If held at zero F., 1000 cubic feet per ton.
If held at 5 degree F., 2000 cubic feet per ton.
If held at 10 degree F., 4000 cubic feet per ton.
If held at 20 degree F., 6000 cubic feet per ton.
If held at 32 degree F., 8000 cubic feet per ton.
If held at 36 degree F., 10000 cubic feet per ton.

The number of cubic feet of well insulated space that can be cooled by one running foot of brine pipe in small rooms up to 1,000 cubic feet capacity:

TABLE XLI

CUBIC SPACE COOLED BY ONE-FOOT PIPE

	1 In. Pipe Cubic Feet	1¼ In. Pipe Cubic Feet	1½ In. Pipe Cubic Feet	2 In. Pipe Cubic Feet
At zero F.	½	⅝	¾	1
At 5 degree F.	1	1¼	1½	2
At 10 degree F.	2	2½	3	4
At 20 degree F.	3	3¾	4½	6
At 32 degree F.	4	5	6	8
At 36 degree F.	5	6¼	7½	10
At 40 degree F.	6	7	8	12
At 50 degree F.	8	9	10	15

Direct Expansion Coils should be arranged free from trap and pockets—each coil should have one regulating and one shut off valve located in engine room and contain:

150 feet of 1 inch pipe per ton of refrigeration.
125 feet of 1¼ inch pipe per ton of refrigeration.
110 feet of 1½ inch pipe per ton of refrigeration.
90 feet of 2 inch pipe per ton of refrigeration.

Expansion Coils should be supplied with one regulating and one shut off valve, and proportioned as follows:

400 feet of 1 inch pipe per ton ice making.
320 feet of 1¼ inch pipe per ton ice making.
270 feet of 1½ inch pipe per ton ice making.
210 feet of 2 inch pipe per ton ice making.

Power Required to Drive Refrigeration Plant.—For large plants, 1¼ to 1½ horse power per ton of refrigeration is the usual allowance of power. On small plants, from 1 to 10 tons capacity, 2 horse power per ton is usually allowed.

When the suction and condensing pressures are known, the mean effective (or average) pressure in the compressor cylinders can be found by the following table.

TABLE XLII

MEAN EFFECTIVE PRESSURE IN COMPRESSOR CYLINDERS

Suction Pressure (Gauge)	CONDENSER PRESSURE (Gauge)					
	150	160	170	180	190	200
5	51	52	54	56	58	60
10	56	58	60	62	64	66
15	62	64	66	68	70	72
20	65	67	69	72	74	76
25	67	69	72	76	78	80
30	68	71	74	78	80	83
40	69	73	76	80	82	86

These figures are taken from an average of a number of cards and are approximately correct, the fraction of a pound being dropped and the nearest whole number taken.

To find the horse power required to drive an ammonia compressor when the suction and condensing pressures are known: Multiply the area of the piston in inches by the mean effective pressure found in the above table and by the speed of the piston in feet per minute, and divide by 33,000.

$$\frac{\text{Area of piston} \times \text{mean effective pressure} \times \text{speed in feet per minute}}{33{,}000} = \text{H. P.}$$

and add to the result 20% to cover the friction of the machine and engine.

EXAMPLE.—Find the horse power required to drive an ammonia compressor having two single-acting compression cylinders 8″ diameter, by 12″ stroke, running at 100 revolutions per minute with 20 pounds suction pressure and 180 pounds condensing pressure.

Area of 8 = 50.29.

$$\frac{50.29 \times 2 \times 100 \times 72}{33{,}000} = 21.94 \text{ H. P.}$$

21.94 + 20% = 26.32 H. P. required to drive the compressor.

When the steam pressure and the point of cut-off are known, the mean effective pressure in the steam cylinder can be found by the following table:

TABLE XLIII

STEAM PRESSURE IN CYLINDERS

Point of Cut-Off	BOILER PRESSURE (Gauge)		
	80	90	100
1-5	33.4	42.15	47.34
1-4	40.85	49.3	55.65
1-3	47.0	53.5	61.5
1-2	64.42	72.89	81.35

To find the horse power of a steam engine: Multiply the area of the piston in inches by the mean effective pressure and by the speed of piston in feet per minute, and divide by 33,000.

$$\frac{\text{Area of piston in inches} \times \text{mean effective pressure} \times \text{speed in feet per minute}}{33{,}000} = \text{H. P.}$$

To find the area of steam piston required when the horse power, speed and mean effective pressure are given: Multiply the horse power by 33,000 and divide by the speed in feet per minute and the mean effective pressure.

Find the diameter of steam cylinder required by an ammonia compressor having two single-acting compression cylinders 8″ diameter by 12″ stroke, running at 100 revolutions per minute with 20 pounds suction pressure and 180 pounds condensing pressure with 80 pounds steam ¼ cut-off. The stroke of the engine to be the same as the compressor.

The compressor requires 26.32 horse power. The mean effective steam pressure is 40.85 pounds. (See table.)

$$\frac{33{,}000 \times 26.32}{2 \times 100 \times 40.85} = \begin{cases} 106.3 \text{ sq. in. area of piston.} \\ \text{or about } 11\frac{5}{8}\text{″ diameter.} \end{cases}$$

For the sake of even measurements, say 12″ diameter for steam piston.

It is common practice to make the steam cylinder of a refrigerating machine two to two and one-quarter times as large as the ammonia cylinder. If the stroke of both cylinders is the same, the area of the steam piston should be two to two and one-quarter times as large as the ammonia piston.

If the strokes are different, the product of the area of the steam piston multiplied by its stroke should

be two to two and one-quarter times the product of the area of the ammonia piston multiplied by its stroke.

Suction Producer Gas Power System.—The term "Suction Producer Gas Power" is descriptive. The system "produces" gas from the coal fed into the "Producer" or "Generator," and this gas is utilized in the gas engine in the same manner as illuminating gas or gasoline is used in the ordinary gas or gasoline engine.

The system consists of a "Producer" in which the gas is formed; "Scrubber," in which the gas is cooled and cleaned; and "Expansion Tank," from which the engine draws its supply; "Gas Engine," where the gas is burned and which delivers the power.

The system is so nearly automatic that it requires the attention of one man only a very small part of his time, meanwhile leaving him free to attend to other duties.

TABLE XLIV

COMPARATIVE OPERATING COSTS

Fuel	Price of Fuel	Fuel Con. per Brake H. P. 10 hours	Cost of Fuel per Brake H. P. 10 hours
Gasoline	12½c per gallon	1¼ gallons	$0.17
Illuminating gas	$1.00 per 1000 cu. ft.	180 cu. ft.	0.18
Bituminous coal in throttling steam engine	4.00 per ton	80 pounds	0.16
Bituminous coal in high speed automatic steam engine	4.00 per ton	60 pounds	0.12
Bituminous coal in simple Corliss steam engine	4.00 per ton	35 pounds	0.07
Bituminous coal in compound condensing Corliss steam engine	4.00 per ton	22½ lbs.	0.04½
Anthracite pea coal in producer gas engine	6.00 per ton	10 pounds	0.03

The nature of the process is such as to make it impossible to waste the fuel as in a steam plant. No smoke-stack is used—all the products of combustion of the coal, after thorough cleaning from tar and ashes, pass through the engine, and, as the engine creates the suction on the system only as much gas is made as is necessary to furnish the power required by the load on the engine.

RATES FOR GENERAL COLD STORAGE PER MONTH

GOODS	RATE
Apples, per bbl	$0.12½
Ale and Beer, per bbl	.25
Ale and Beer, per ½ bbl	.15
Ale and Beer, per ¼ bbl	.10
Beer, bottled, per case	.10
Beer, bottled, per cask	.20
Berries, per basket	½
Butter and Butterine, per lb	⅛
Butter and Butterine, small lot	.50
Calves, each, per day	.10
Calves, per lb	½
Canned Goods, per lb	⅛
Cured Meats, per cask or case	.25
Cider, per cask	.25
Cheese, per lb	⅛
Celery, per case	.10
Cranberries, per case	.10
Cranberries, per cask	.20
Dried Fruit, per lb	⅛
Dried Fish, per lb	¼
Eggs, per case	.12½
Furs, undressed, per lb. (Hydraulic Pressed)	¼
Furs, dressed, per lb	.03
Grapes, per lb	½
Hops, per lb	⅛
Lard, per tierce	.25
Lard Oil, per case	.25
Lemons, per box	.15
Maple Sugar, per lb	¼

GOODS	RATE
Maple Syrup, per gal.	½
Nuts, per lb.	⅛
Oleomargarine, per lb.	⅛
Onions, per bbl.	.12½
Onions, per box	.15
Oil, per cask	.25
Oil, per hhd.	1.00
Oysters, in tubs, per gal.	.05
Oysters, in shell, per bbl.	.50
Pears, per case	.15
Peaches, per lb.	½
Pork, per tierce	.20
Sauerkraut, per cask	.25
Syrup, per gal.	½
Tobacco, per lb.	⅛
Vegetables, per bbl.	.25
Vegetables, per case	.15
Wine, in wood, per cask	.25
Wine, in bottle, per case	.10

SEASON RATES

GOODS	SEASON RATE	ENDS
Apples, per bbl.	$0.50	, May 1
Butter, per lb.	½	, Jan. 1
Butterine, per lb.	½	, Jan. 1
Cheese, per lb.	½	, Jan. 1
Dried Fruit, per lb.	⅜	, Nov. 1
Dried Fish, per lb.	.01	, Nov. 1
Eggs, per case, received prior to July 1st	.60	, Jan. 1
Eggs, per case, received after July 1st	.50	, Jan. 1
Furs, undressed per lb. (Hydraulic Pressed)	.01	, Nov. 1
Furs, dressed, per lb.	.10	, Nov. 1
Grapes, per lb.	.02	, Jan. 1
Lemons, per box	.50	, Nov. 1
Lard, per tierce	1.00	, Nov. 1
Nuts, per lb.	⅜	, Nov. 1
Oranges, per box	.50	, Nov. 1
Onions, per bbl.	.60	, May 1
Pears, per case	.50	, May 1
Peaches, per lb.	.02	, Jan. 1
Sauerkraut, per cask	.75	, Nov. 1

TABLE XLV—Continued

COLD STORAGE TEMPERATURES

COLD STORAGE TEMPERATURES ARTICLES	Degrees Fahr. Cold Storage Temperature	LOWEST AND HIGHEST TEMPERATURES TO WHICH PERISHABLE GOODS MAY BE SUBJECTED WITHOUT INJURY. Lowest Outside Temperature. Articles in Ordinary Packages	In Ordinary Fr't Cars	In Refrigerator or Specially Prepared Cars	Temperature above which Injury Occurs	HOW PACKED
Cymlings or squashes		32	22		75	In crates
Dates	55					
Deer		Zero	20		65	Shipped loose
Dress poultry (iced)	30					
Dried beef	40					
Dried corn	45					
Dried fish	40					
Dried fruits	40					
Drugs (non-alcoholic)		32	28	Zero		
Eggs, barreled or crated	30	30	20	Zero	80	
Endive		10	Zero		70	In boxes or crates
Extract beef		25	15	10		
Extracts (flavoring)		20	15	Zero		
Fabric and Fur room	28	28				
Fern balls, Japanese	31					
Ferns	28					
Field grown roses	32					
Figs	55					
Fish		10	Zero		65	Barrels always iced
Fish, canned		18	15	10		
Fish, (not frozen, short carry)	28					
Fish, fresh water (after frozen)	18					
Fish, salt water (after frozen)	15					
Fish, to freeze	5					
Flour, buckwheat and wheat	42					

TABLE XLV—Continued

COLD STORAGE TEMPERATURES

COLD STORAGE TEMPERATURES		LOWEST AND HIGHEST TEMPERATURES TO WHICH PERISHABLE GOODS MAY BE SUBJECTED WITHOUT INJURY. LOWEST OUTSIDE TEMPERATURE.				
ARTICLES	Degrees Fahr. Cold Storage Temperature	Articles in Ordinary Packages	In Ordinary Fr't Cars	In Refrigerator or Specially Prepared Cars	Temperature above which Injury Occurs	HOW PACKED
Canned meats	40					
Canned tomatoes		28	25	5		
Cantaloupes (short carry)	40	32	25	10	80	
Cantaloupes (1 to 2 mos.)	40					
Carrots	33	30	25	20		
Casings, Sausage	20					
Catsup		25	15	10		
Cauliflower		22	15		70	Barrels with straw
Caviar	36					
Celery	31	10	Zero		65	Packed in crates
Cheese (long carry)	35	30	25	10	75	
Chestnuts	34					
Chocolate dipping room	65					
Cider	31	22	18	10	70	
Cigars	42					
Clam broth and juice		30	20	10	80	
Clams in shell		20	10	10	65	In barrels
Cocoanuts		30	20	Zero	90	In barrels or crates
Corn, dried	45					
Corn meal	42					
Crabs		10	Zero		65	In baskets and barrels
Cranberries	33	28	20	Zero		
Cucumbers	38	32	20		65	In boxes with moss
Currants (few days only)	31					
Cut roses	36					

TABLE 21.4 Continued

COLD STORAGE TEMPERATURES

	Temperature Range (Fahrenheit)	Relative Humidity (Per Cent)	Temperature (Fahrenheit)	Relative Humidity (Per Cent)	Temperature Above Which Injury Occurs	
[illegible]	10					
[illegible]	70					
[illegible]	38	85	30	80	75	In boxes or crates
[illegible]		80	75		70	In boxes or crates
[illegible]	28					
[illegible]	30					
[illegible]		85	30	Zero		
Mandarins		85	30	Zero	75	In boxes
Maple sugar	45					
Maple syrup	45					
Manta (salted)	40					
Manta (suet) (few days only)	35					
Manta (suet) (10 to 30 days)	30					
Manta, (suet) curing room	35					
Meat gall (after curing)	45					
Mellolima, patent		82	28	Zero		In sawdust
Milk		82	28	Zero	75	
Muntingia		85	15	Zero		
Mustard, French		80	30	10		
Nursery stock	30					
Nuts in shell	40					
Oat meal	42					
Oleomargarine	20					
Oils	45					
Okra		85	30		75	In baskets or boxes

TABLE XLV—Continued

COLD STORAGE TEMPERATURES

COLD STORAGE TEMPERATURES		LOWEST AND HIGHEST TEMPERATURES TO WHICH PERISHABLE GOODS MAY BE SUBJECTED WITHOUT INJURY. LOWEST OUTSIDE TEMPERATURE.				
ARTICLES	Degrees Fahr. Cold Storage Temperature	Articles in Ordinary Packages	In Ordinary Fr't Cars	In Refrigerator or Specially Prepared Cars	Temperature above which Injury Occurs	HOW PACKED
Olives in bulk		28	25	Zero		In barrels
Olives in glass		25	20	Zero		
Onions	32	20	10	Zero	80	In barrels or crates
Oranges (short carry)	50					
Oranges (long carry)	34	28	20		80	In baskets, barrels or crates
Ox tails	30					
Oysters (iced in tubs)	35	30	20	Zero		
Oysters (in shell)	43	20	10	10	65	In barrels
Palm seeds	38					
Parsley		32	20		75	In baskets
Parsnips		32	20		70	In baskets or barrels
Partridges		10	Zero		65	In bunches in boxes
Pastes		32	25	10		In barrels
Peaches, canned		20	15	Zero		
Peaches, fresh, baskets	32	32	20	10	80	
Peaches (short carry)	50					
Peach butter	42					
Pears	33	32	20	10	80	
Peas		32	20		80	In baskets or barrels
Pickles in bulk		22	18	10		In barrels
Pickles in glass		20	16	10		
Pickled salmon (mild cured)	33					
Pineapples		32	25	Zero	75	In barrels or crates
Pips Lily of the Valley	28					
Plums (1 to 2 mos.)	32	35	32	Zero	75	In boxes with paper

TABLE XLV—Continued

COLD STORAGE TEMPERATURES

COLD STORAGE TEMPERATURES		LOWEST AND HIGHEST TEMPERATURES TO WHICH PERISHABLE GOODS MAY BE SUBJECTED WITHOUT INJURY. Lowest Outside Temperature.				
ARTICLES	Degrees Fahr. Cold Storage Temperature	Articles in Ordinary Packages	In Ordinary Fr't Cars	In Refrigerator or Specially Prepared Cars	Temperature above which Injury Occurs	HOW PACKED
Potatoes, Irish	34	33	25	10	80	In barrels or baskets
Potatoes, sweet		35	28	10	80	In barrels or baskets
Poultry (short carry)	28					
Poultry (after frozen)	28					
Poultry (to freeze)	0					
Poultry, dressed (iced)	30					
Preserves		20	10	10		
Radishes		20	15		65	In baskets
Raisins	55					
Ribs (not brined)	20					
Rice		20	10		90	In barrels and sacks
Room chocolate dipping	65					
Room Fur and Fabric	28					
Room salt meat curing	33					
Roses, cut	36					
Roses, field grown	32					
Salt meat curing room	33					
Sardines, canned	40					
Sauerkraut	38					
Sausage casings	20					
Scallops (after frozen)	16					
Seeds, Palm	38					
Shoulders (not brined)	20					
Shrubs, roses or trees		35	10	10		In canvas or sacking
Spinach		15	15		75	In barrels or crates

TABLE XLV—Continued

COLD STORAGE TEMPERATURES

COLD STORAGE TEMPERATURES — ARTICLES	Degrees Fahr. Cold Storage Temperature	LOWEST AND HIGHEST TEMPERATURES TO WHICH PERISHABLE GOODS MAY BE SUBJECTED WITHOUT INJURY. Lowest Outside Temperature. — Articles in Ordinary Packages	In Ordinary Fr't Cars	In Refrigerator or Specially Prepared Cars	Temperature above which Injury Occurs	HOW PACKED
Strained honey	45					
Strawberries		33	25	10	65	
Sugar	45					
Sugar, maple	45					
Syrup	45					
Syrup, maple	45					
Tangerines		25	15	Zero	70	In boxes
Tea plants		28	20			In boxes
Tenderloin, etc	33					
Thyme		20	10		90	In small baskets
Tobacco	42					
Tomatoes, canned		28	25	5		In boxes
Tomatoes, fresh	42	33	28	10	90	
Turnips, late		15	Zero		75	In barrels
Vinegar, barrels		22	18	10		
Watermelons (short carry)	40	20	10		85	In barrels or bulk
Wheat flour	42					
Wild boar		Zero	20		65	Shipped loose
Wild turkey		Zero	20		65	Shipped loose
Wines, light		22	15	Zero		
Wines	50					
Yeast		28	25	Zero	65	

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